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Environmental Assessment of a Wood-Waste-Fired Industrial Firetube Boiler Volume 1. Technical Results

Acurex Corp., Mountain View, CA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

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ENVIRONMENTAL ASSESSMENT
OF A WOOD-WASTE-FIRED
INDUSTRIAL FIRETUBE BOILER
Volume I. Technical Results

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

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16. ABSTRACT The report gives emission results from field tests of a wood-waste-fired industrial firetube boiler. Emission measurements included: continuous monitoring of flue gas emissions; source assessment sampling system (SASS) sampling of the flue gas with subsequent laboratory analysis of samples to give total flue gas organics in two boiling point ranges, compound category information within these ranges, specific quantitation of the semivolatile organic priority pollutants, and flue gas concentrations of 65 trace elements; Method 5 sampling for particulates; controlled condensation system (CSS) sampling for SO2 and SO3; and grab sampling of boiler bottom ash for trace element content determinations. Flue gas CO emissions were quite variable during the tests, and often quite high (attributed to the high excess air level at which the unit operated). NOx emissions were relatively high for a wood-fired boiler, although the fuel nitrogen content was relatively high for a wood fuel. SO2 and SO3 emissions were less than 10 ppm, in keeping with the low sulfur content of the wood-waste fuel. Total organic emissions from the boiler were 5.7 mg/dscm, about 90% of which consisted of volatile compounds. Emission levels of five polycyclic organic matter species and phenol were quantitated: except for naphthalene, all were emitted at less than 0.4 microgram/dscm.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Pollution	Sulfur Oxides	Pollution Control	13B 07B
Wood Wastes	Nitrogen Oxides	Stationary Sources	11L
Fire Tube Boilers	Trace Elements	Environmental Assessment	13A 06A
Flue Gases	Carbon Monoxide		21B
Assessments	Organic Compounds	Particulate	14B 07C
Particles	Polycyclic Compounds		14G
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ENVIRONMENTAL ASSESSMENT OF A WOOD-WASTE-FIRED INDUSTRIAL FIRETUBE BOILER

Volume I. Technical Results

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SECTION 1

INTRODUCTION

This report describes and presents results for a set of environmental assessment tests performed for the Industrial Environmental Research Laboratory/Research Triangle Park (IERL-RTP)* of EPA under the Combustion Modification Environmental Assessment (CMEA) program, EPA Contract no. 68-02-3188. The CMEA started in 1976 with a 3-year study, the NO_x Control Technology Environmental Assessment (NO_x EA, EPA contract no. 68-02-2160), having the following four objectives:

- Identify potential multimedia environmental effects of stationary combustion sources and combustion modification technology
- Develop and document control application guidelines to minimize these effects
- Identify stationary source and combustion modification R&D priorities
- Disseminate program results to intended users

During the first year of the NO_x EA data for the environmental assessment were compiled and methodologies were developed. Furthermore, priorities for the schedule and level of effort for the various source/fuel/control combinations were identified. This effort revealed major

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*Now designated EPA's Air and Energy Engineering Research Laboratory.

data gaps, particularly for noncriteria pollutants (organic emissions and trace elements) for virtually all combinations of stationary combustion sources and combustion modification techniques. Consequently, a series of seven environmental field test programs was undertaken to fill these data gaps. The results of these tests are documented in seven individual reports (References 1-1 through 1-7) and in the NO_x EA final report summarizing the entire 3-year effort (Reference 1-8).

The current CMEA program has, as major objectives, the continuation of multimedia environmental field tests initiated in the original NO_x EA program. These new tests, using standardized sampling and analytical procedures (Reference 1-9) are aimed at filling the remaining data gaps and addressing the following priority needs:

- Advanced NO_x controls
- Alternate fuels
- Secondary sources
- EPA program data needs
  - -- Residential oil combustion
  - -- Wood firing in residential, commercial, and industrial sources
  - -- High interest emissions determination (e.g., listed and candidate hazardous air pollutant species)
- Nonsteady-state operations

As part of the effort to support EPA program needs for data on wood combustion, two industrial boilers were tested under the CMEA program. For this test, an industrial firetube boiler burning a mixture of pine, oak, and hickory with glue and ground up masonite was selected. This boiler can be considered representative of the wood-fired industrial boiler population

within the forest products industries of the southeastern United States. The objective of this test was to sample stack emissions and solid waste discharges and identify pollutants of potential concern using standardized sampling and analytical procedures.

The results of the other wood-fired boiler test, contrasting the effects of burning dry and green wood waste in an industrial watertube boiler, are documented in a separate report under the current CMEA program (Reference 1-10).

Table 1-1 lists all the tests performed in the CMEA program, outlining the source tested, fuel used, combustion modifications implemented and the level of sampling and analysis performed in each case. Results of these test programs are discussed in separate reports.

TABLE 1-1. COMPLETED TESTS DURING THE CURRENT PROGRAM

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Spark ignited natural gas-fired reciprocating internal combustion engine	Large bore, 6-cylinder, opposed piston, 186 kW (250 Bhp)/cyl, 900 rpm, Model 38TDS8-1/8	-- Baseline (pre-NSPS) -- Increased air-fuel ratio aimed at meeting proposed NSPS of 700 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Compression ignition diesel-fired reciprocating internal combustion engine	Large bore, 6-cylinder opposed piston, 261-kW (350 Bhp)/cyl, 900-rpm, Model 38TDD8-1/8	-- Baseline (pre-NSPS) -- Fuel injection retard aimed at meeting proposed NSPS of 600 ppm corrected to 15 percent O_2 and standard atmospheric conditions	Engine exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Lube oil	Fairbanks Morse Division of Colt Industries
Low-NO_x residential condensing heating system furnished by Karlsons Blueburner Systems Ltd. of Canada	Residential hot water heater equipped with M.A.N. low-NO_x burner, 0.55 ml/s (0.5 gal/hr) firing capacity, condensing flue gas	Low-NO_x burner design by M.A.N.	Furnace exhaust: -- SASS -- Method 8 -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel Waste water	New test
Rocketdyne/EPA low-NO_x residential forced warm air furnace	Residential warm air furnace with modified high pressure burner and firebox, 0.83 ml/s (0.75 gal/hr) firing capacity	Low-NO_x burner design and integrated furnace system	Furnace exhaust: -- SASS -- Method 8 -- Controlled condensation -- Method 5 -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2, CH_4, TUHC Fuel	New test

TABLE 1-1. CONTINUED

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Pulverized coal-fired utility boiler, Conesville station	400-MW tangentially fired; new NSPS design aimed at meeting 301 ng/J NO_x limit	ESP inlet and outlet, one test	ESP inlet and outlet: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous NO, NO_x, CO, CO_2, O_2 Coal Bottom ash ESP ash	Exxon Research and Engineering (ER&E) conducting corrosion tests
Nova Scotia Technical College industrial boiler	1.14 kg/s steam (9,000 lb/hr) firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with limestone injection	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, CO_2, CO, NO Fuel	Envirocon performed particulate and sulfur emission tests
Adelphi University industrial boiler	1.89 kg/s steam (15,000 lb/hr) hot water firetube fired with a mixture of coal-oil-water (COW)	-- Baseline (COW) -- Controlled SO_2 emissions with Na_2CO_3 injection	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Controlled condensation -- Gas Sample (C_1 - C_6 HC) -- Continuous O_2, CO_2, NO, CO Fuel	Adelphi University
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-oil (COM)	-- Baseline test only with COM	Boiler outlet: -- SASS -- Method 5 -- Controlled condensation -- Continuous O_2, CO_2, NO, TUHC, CO -- N_2O grab sample Fuel	PETC and General Electric (GE)

TABLE 1-1. CONTINUED

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
TOSCO Refinery vertical crude oil heater	2.54 Ml/day (16,000 bbl/day) natural draft process heater burning oil/refinery gas	-- Baseline -- Staged combustion using air injection lances	Heater outlet: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO, CO, CO_2, HC -- N_2O, grab sample Fuel oil Refinery gas	KVB coordinating the staged combustion operation and continuous emission monitoring
Mohawk-Getty Oil industrial boiler	8.21 kg/s steam (65,000 lb/hr) watertube burning mixture of refinery gas and residual oil	-- Baseline -- Ammonia injection using the noncatalytic Thermal DeNO$_x$ process	Economizer outlet: -- SASS -- Method 5, 17 -- Controlled condensation -- Gas Sample (C_1 - C_6 HC) -- Ammonia emissions -- N_2O grab sample -- Continuous O_2, NO, CO, CO_2 Fuels (refinery gas and residual oil)	New test
Industrial boiler	2.52 kg/s steam (20,000 lb/hr) watertube burning woodwaste	-- Baseline (dry wood) -- Green wood	Boiler outlet: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO, CO Fuel Flyash	North Carolina Department of Natural Resources, EPA IERL-RTP
Industrial boiler	3.16 kg/s steam (29,000 lb/hr) firetube with refractory firebox burning woodwaste	-- Baseline (dry wood)	Outlet of cyclone particulate collector: -- SASS -- Method 5 -- Controlled condensation -- Gas sample (C_1 - C_6 HC) -- Continuous O_2, NO$_x$, CO Fuel Bottom ash	North Carolina Department of Natural Resources, EPA IERL-RTP

TABLE 1-1. CONTINUED

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Enhanced oil recovery steam generator	15 MW (50 million Btu/hr) steam generator burning crude oil equipped with MHI low-NO_x burner	-- Performance mapping -- Low NO_x operation	Steamer outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1 - C_6 HC) Continuous O_2, NO_x, CO, CO_2 N_2O grab sample Fuel	Getty Oil Company, CE-Natco
Pittsburgh Energy Technology Center (PETC) industrial boiler	3.03 kg/s steam (24,000 lb/hr) watertube fired with a mixture of coal-water (CWM)	-- Baseline test only with CWM	Boiler outlet: -- SASS -- Method 5 -- Method 8 -- Gas sample (C_1 - C_6 HC) Continuous O_2, NO_x, CO, CO_2, TUHC N_2O grab sample Fuel Bottom ash Collector hopper ash	PETC and General Electric
Internal combustion engine -- nonselective NO_x catalyst	818 HP Waukesha engine equipped with DuPont NSER catalyst	-- Baseline -- 15-day emissions monitoring	Catalyst inlet and outlet -- SASS -- NH_3 -- HCN -- Grab sample N_2O -- Continuous O_2, CO_2, NO_x, TUHC Fuel	Southern California Gas Company
Industrial boiler	180 kg/hr steam (400 lb/hr) stoker fired with a mixture of coal and waste plastic	-- Baseline (coal) -- Coal and plastic waste	Boiler outlet -- SASS -- VOST -- Method 5/8 -- HCl -- Continuous O_2, NO_x, CO, CO_2, TUHC -- N_2O grab sample Fuel Bottom ash Cyclone ash	Vermont Agency of Environmental Conservation

TABLE 1-1. CONCLUDED

Source	Description	Test points unit operation	Sampling protocol	Test collaborator
Industrial boiler	7.6 kg/s steam (60,000 lb/hr) watertube retrofit for coal water mixture firing	-- Baseline test with CWS -- 30-day emissions monitoring	Boiler outlet -- SASS -- VOST -- Method 5 -- Method 8 -- Gas sample (C_1-C_6 HC) -- N_2O grab sample -- Continuous NO_x, CO, CO_2, O_2, TUHC, SO_2 Fuel	EPRI, DuPont
Enhanced oil recovery steam generator	15-MW (50 million Btu/hr) steam generator burning crude oil, equipped with the EPA/EER low-NO_x burner	-- Low NO_x (with burner) -- 30-day emissions monitoring	Steamer outlet -- SASS -- VOST -- Method 5 -- Method 8 -- Controlled condensation -- Anderson impactor -- Gas sample (C_1-C_6 HC) -- N_2O grab sample -- Continuous NO_x, CO, CO_2, O_2, SO_2 Fuel	Chevron U.S.A., EERC
Spark-ignited natural-gas-fired reciprocating internal combustion engine -- selective NO_x reduction catalyst	1,490-kW (2,000-hp) Ingersoll-Rand lean-burn engine equipped with Englehard SCR system	-- Low NO_x (with catalyst) -- 15-day emissions monitoring	Catalyst inlet and outlet -- SASS -- VOST -- NH_3 -- HCN -- N_2O grab sample -- Continuous O_2, CO_2, CO, NO, NO_x, NO_x+NH_3 Lube oil	Southern California Gas Company

[a]Acronyms used in the table: EERC, The Energy and Environmental Research Corporation; EPA IERL-RTP, The Environmental Protection Agency's Industrial Environmental Research Laboratory -- Research Triangle Park; EPRI, The Electric Power Research Institute; HC, hydrocarbons; NSCR, nonselective catalytic reduction; NSPS, new source performance standard; SASS, source assessment sampling system; SCR, selective catalytic reduction; TUHC, total unburned hydrocarbon; VOST, volatile organic sampling train

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SECTION 2

SOURCE DESCRIPTION

The tests were performed on a McBurney horizontal return tube firetube boiler designed to fire wood waste. The boiler has a three pass design with flyash reinjection. Rated capacity is 3.15 kg/s saturated steam (25,000 lb/hr) at 1.0 MPa (150 psi). The boiler, located at a furniture manufacturing plant, was selected because it is representative of the unit design widely employed in the forest products industries in the southeastern United States and because it was the site of an organic emissions evaluation program by the North Carolina Department of Natural Resources and Community Development (DNR). Results from the CMEA test program on this unit provided additional data to the DNR program as well as duplicate data allowing for complete environmental assessment and data validity evaluation to the mutual benefit of both programs.

Figure 2-1 presents a diagram of the boiler and associated equipment, noting the sampling locations used. The unit normally burns kiln-dried mill residue (a mixture of pine, oak, hickory, glue and ground masonite) blown into the boiler by a pair of wood feeder blowers. After combustion, the flue gas proceeds through the three heat exchanger passes. Total heat exchange area is 372 m^2 (4,000 ft^2). Before entering the stack, the flue gas passes through a multicyclone which separates the larger particles of flyash for reinjection.

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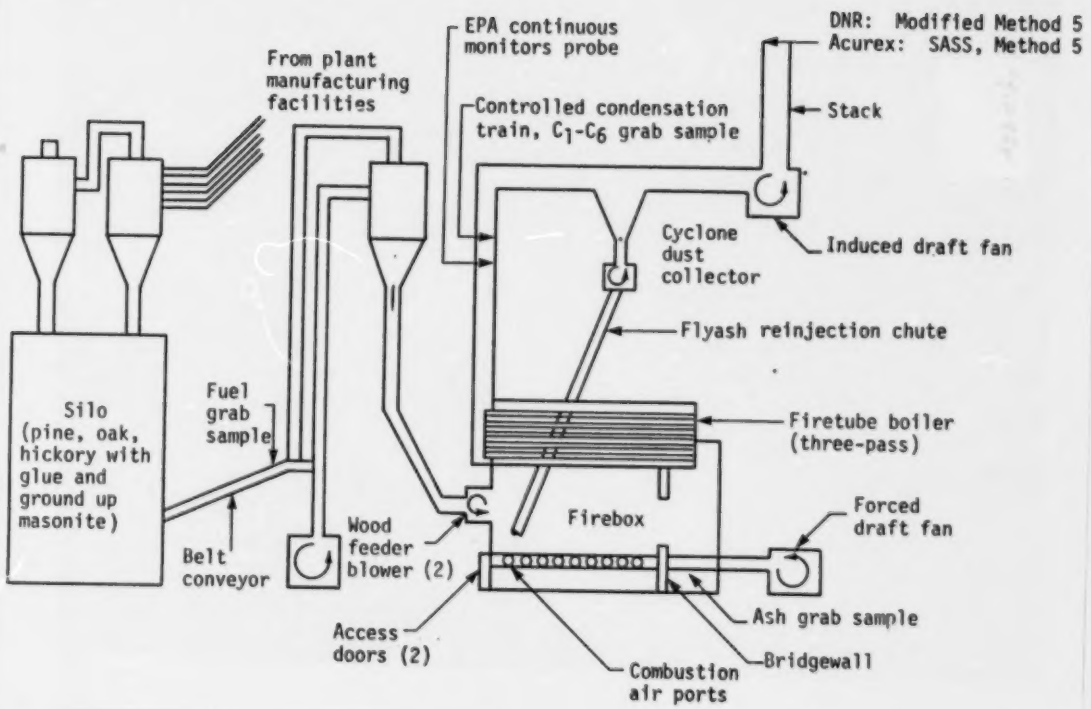

Figure 2-1. Boiler schematic.

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Table 2-1 summarizes the boiler operating conditions during the test performed. The fuel ultimate analysis is given in Table 2-2. The test was conducted over a 6-hour period with no unusual difficulties. However, because of the relatively high excess air level over the test period (160 percent), boiler efficiency was a modest 64.5 percent, based on the ASME heat loss calculation method. The woodwaste flowrate noted in Table 2-1 is not a measured value. It was calculated based on measured stack gas flowrate (Method 5) and O_2 level, and the fuel analysis. This value should be treated with caution. If the expected steam flowrate is calculated based on the fuel flowrate and heating value, and the boiler efficiency noted in Table 2-1, a value of 2.4 kg/s (19,400 lb/hr) results. This contrasts with the control panel steam meter reading of 1.7 kg/s (13,600 lb/hr). The calculated value (2.4 kg/s) is more likely to be nearly correct.

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TABLE 2-1. BOILER OPERATING CONDITIONS

Steam flow, kg/s (10^3 lb/hr)	1.71 (13.6)
Drum pressure, MPa (psig)	0.841 (122)
Feedwater pressure, MPa (psig)	1.09 (158)
Outlet pressure, kPa (in. H_2O)	0.25 (1.0)
Collector pressure, kPa (in. H_2O)	0.54 (2.1)
Stack temperature, °C (°F)	343 (650)
Ambient air, °C (°F)	25 (77)
Wood feed rate, kg/s (lb/hr)[a]	0.514 (4,070)
Excess air, percent[b]	160
Boiler efficiency, percent[c]	64.5

[a]As fired, calculated from stack gas flow, O_2, and fuel analysis
[b]Calculated from the O_2 measurements and fuel analysis
[c]Based on heat loss method

TABLE 2-2. ULTIMATE FUEL ANALYSIS (PERCENT BY WEIGHT)[a]

Carbon, C	47.60
Hydrogen, H	5.75
Nitrogen, N	0.18
Sulfur, S	0.04
Oxygen, O (by difference)	45.93
Ash	0.50
Moisture[b]	5.66
Higher heating value, kJ/kg (Btu/lb)	20,060 (8,630)

[a]Dry basis, except as noted
[b]As received

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SECTION 3

EMISSION RESULTS

The objective of this test program was to measure flue gas emissions and pollutant concentrations in the bottom ash stream from a wood-waste-fired firetube boiler under as-found operating conditions. Emission measurements were performed in cooperation with the North Carolina Department of Natural Resources and Community Development (DNR), whose team was onsite to perform a polycyclic organic matter (POM) emissions evaluation (Reference 3-1).

3.1 SAMPLING PROTOCOL

The boiler sampling protocol included the following procedures:

- Source Assessment Sampling System (SASS)
- Controlled Condensation System (CCS) (SO_2, SO_3)
- Grab sample for C_1 to C_6 hydrocarbon measurement
- EPA Method 5 (particulate)
- Continuous monitors for O_2, CO and NO_x
- Fuel grab sample
- Bottom ash grab sample

Sampling and analysis procedures conformed to a modified EPA Level 1 protocol (Reference 3-2). SASS and Method 5 measurements were taken at the stack. The CCS train, the continuous monitors, and the gas grab samples for C_1 to C_6 hydrocarbon analysis were taken at the boiler outlet, upstream of

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the mechanical particulate collector. The continuous monitoring of flue gas O_2, CO, and NO_x was performed by EPA-IERL/RTP personnel.

3.2 CRITERIA POLLUTANT AND OTHER VAPOR SPECIES EMISSIONS

Table 3-1 summarizes gaseous and particulate emission measurements during the test. Continuous monitoring equipment, including a gas conditioning system, were used to measure O_2, CO, and NO_x. As shown, flue gas O_2 was quite high during the test, even for wood-fired boilers which normally operate at high excess air. The excess air level corresponding to the average flue gas O_2 in Table 3-1 is about 160 percent.

NO_x emissions averaged 154 ng/J. This is at the high end of the range typically cited for industrial wood-fired units (Reference 3-3), and is higher than that measured from the other wood-fired boiler tested under the CMEA program (Reference 3-4). The relatively high NO_x emissions from this unit are most likely explained by the high nitrogen content of the fuel (0.18 percent). Most wood fuels contain less than 0.1 percent nitrogen.

The CO emissions are of interest in this test because of their extreme variability and relatively high levels. As noted in Table 3-1, CO emissions varied from about 40 ppm (dry) to over 2,200 ppm. The variation in CO emissions with changing flue gas O_2 levels is shown in figure 3-1. The figure shows that when flue gas O_2 was below 12 percent, CO emissions were below 200 ppm (dry at 3 percent O_2). However, as flue gas O_2 increased above 12 percent, CO emissions rapidly increased, to well over 1,000 ppm (at 3 percent O_2) at flue gas O_2 above 15 percent. This suggests that, under the conditions of this test, the flame was being quenched by the large amount of excess air fired.

TABLE 3-1. FLUE GAS EMISSIONS

Uncorrected	Range	Average
O_2, percent dry	11.0 to 16.8	13.1
CO, ppm dry	38 to 2,257	NA[a]
NO_x, ppm dry	33 to 603	134
Moisture, percent	b	5.54

Corrected	ppm[c]	ng/J	g/kg[d]
NO (average as NO_2)	305	154	2.96
Particulate	mg/dscm		
SASS	190	114	2.15
Method 5			
Solid	180	108	2.04
Condensible	1.9	1.1	0.021
DNR Method 5[e]			
Solid	200	127	2.40

[a]Not applicable, data variability too wide to allow defining meaningful average
[b]Extractive sample, range not applicable
[c]At 3 percent O_2, dry
[d]As fired (wet) basis
[e]Reference 3-1, average of two runs

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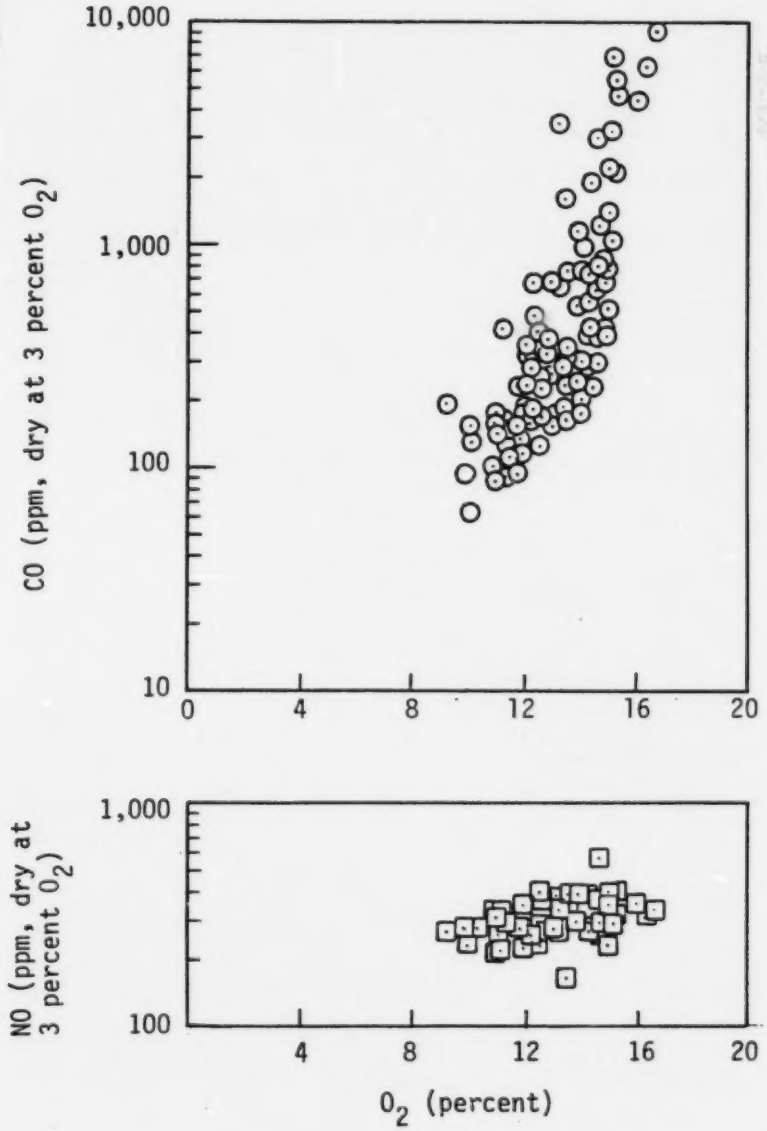

Figure 3-1. CO and NO_x emissions versus flue gas O_2.

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The NO_x emissions, also shown in Figure 3-1, exhibit no strong variation with flue gas O_2; NO_x emissions essentially stayed in the 200 to 400 ppm range (dry at 3 percent O_2) over the range in O_2 of 10 to 16 percent.

SO_2 or SO_3 in the flue gas were below a detection limit of 10 ppm using the CCS method with subsequent wet chemical analyses. This method normally has a detection limit of below 1 ppm. However, problems encountered in the laboratory titration of samples collected in the field (see Appendix A) resulted in an increased detection limit of about 10 ppm. The fact that SO_2 and SO_3 emissions were below 10 ppm is not surprising, considering the low sulfur content of the fuel (0.04 percent). In fact, assuming 100 percent conversion of the fuel sulfur to SO_2, maximum SO_2 concentrations would be only 26 ppm at stack conditions.

Particulate emissions were measured at 190 mg/dscm by the SASS train, 180 mg/dscm by this program's Method 5 train and 200 mg/dscm by the DNR Method 5 train, all in good agreement.

The particulate size distribution obtained by the SASS train is summarized in Table 3-2. Approximately half of the particulate is less than 1 μm, which would be expected from a unit using flyash reinjection.

3.3 TRACE ELEMENT EMISSIONS

Trace element concentrations in the wood fuel, bottom ash, and the SASS catches were measured using atomic absorption spectroscopy (AAS) for mercury, antimony, and arsenic, and spark source mass spectroscopy (SSMS) for 62 other elements. Analysis results on the SASS catches were used to calculate flue gas concentrations of these elements. These are presented in Appendix B. However, trace element flowrates and mass balance estimated could not be established since the bottom ash generation rate was not measured.

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TABLE 3-2. PARTICULATE SIZE DISTRIBUTION

Particulate cut size	Emissions		
	ng/J	mg/dscm	Percent of total particulate
>10 μm (10 μm cyclone plus probe wash)	26	44	23.1
3 to 10 μm (3 μm cyclone)	18	29	15.5
1 to 3 μm (1 μm cyclone)	12	20	10.5
<1 μm (filter)	58	97	50.9
Total	114	190	100.0

Table 3-3 shows trace element concentrations in the wood fuel (as fired), the bottom ash, and the SASS particulate in two size ranges. The data in the table show a clear pattern of trace element enrichment in the coarse (>3 μm) particulate over the bottom ash. That is, the concentration (μg/g) of most elements analyzed is greater in the coarse particulate than in the bottom ash. However, this enrichment pattern does not extend into the fine (<3 μm) particulate; concentrations of most elements noted are less in the fine particulate than in the coarse particulate, or even the bottom ash. Similar results were noted in the trace element analysis data obtained in tests of the other wood-fired boiler tested in the CMEA (Reference 3-4). This is the opposite of the normal occurrence in coal-fired sources, where many elements are further enriched in the fine particulate.

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TABLE 3-3. TRACE ELEMENT CONCENTRATIONS (µg/g)

Element	Wood fuel	Bottom ash	Particulate	
			10 + 3 µm	1 µm + filter
Aluminum	2.0	>1,000	>1,000	a
Antimony	a	a	a	a
Arsenic	a	a	a	a
Barium	21	>1,000	>1,000	1,000
Beryllium	<0.010	0.20	0.20	a
Bismuth	a	a	a	<0.52
Boron	0.20	280	570	a
Bromine	0.20	4.0	21	a
Cadmium	0.090	0.80	17	1.0
Calcium	>100	>1,000	>1,000	>2,100
Cerium	0.60	66	240	4.7
Cesium	<0.010	0.70	1.0	<0.52
Chlorine	22	110	>1,000	1,500
Chromium	0.030	52	100	4.7
Cobalt	0.090	3.0	17	0.52
Copper	2.0	61	170	15
Dysprosium	a	2.0	4.0	<0.52
Erbium	a	0.40	2.0	<0.52
Europium	<0.010	1.0	2.0	<0.52
Fluorine	0.40	160	140	210
Gadolinium	0.010	2.0	5.0	<0.52
Gallium	0.040	7.0	7.0	a
Germanium	0.010	0.30	2.0	0.52
Hafnium	a	0.30	a	<0.52
Holmium	a	1.0	3.0	<0.52
Iodine	0.030	0.50	3.0	a
Iron	12	>1,000	>1,000	68
Lanthanum	0.50	120	240	4.7
Lead	0.20	82	170	260
Lithium	0.070	65	3.0	1.0
Lutetium	a	<0.10	0.40	<0.52
Magnesium	>100	>1,000	>1,000	a
Manganese	17	>460	>920	>150
Mercury	<0.050	<0.050	<1.0	<0.43
Molybdenum	0.020	13	20	2.6

[a]Element not detected

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TABLE 3-3. CONCLUDED

Element	Wood fuel	Bottom ash	Particulate	
			10 + 3 μm	1 μm + filter
Neodymium	0.020	22	25	1.6
Nickel	0.20	75	300	14
Niobium	0.010	1.0	2.0	1.0
Phosphorus	57	>1,000	>1,000	>310
Potassium	>62	>1,000	>1,000	>52
Praseodymium	0.060	10	21	a
Rubidium	0.40	260	520	51
Samarium	0.050	9.0	19	0.52
Scandium	<0.010	1.0	<0.10	a
Selenium	0.60	2.0	28	0.52
Silicon	17	>1,000	>1,000	a
Silver	<0.010	a	17	2.6
Sodium	>13	>1,000	>1,000	a
Strontium	3.0	>1,000	>1,000	48
Sulfur	6.0	>1,000	>1,000	a
Tantalum	a	a	3.0	<0.52
Tellurium	<0.010	0.30	0.70	<0.52
Terbium	<0.010	0.90	2.0	<0.52
Thallium	a	a	0.60	a
Thorium	a	0.90	1.0	<0.52
Thulium	a	<0.010	0.30	<0.52
Tin	0.020	2.0	8.0	1.0
Titanium	3.0	>1,000	>1,000	a
Tungsten	a	25	89	21
Uranium	a	0.40	<0.60	<0.52
Vanadium	<0.040	15	9.0	a
Ytterbium	a	0.50	2.0	<0.52
Yttrium	0.070	15	40	0.52
Zinc	3.0	240	>1,000	520
Zirconium	0.30	7.0	15	a

[a]Element not detected

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3.4 ORGANIC SPECIES EMISSIONS

Organic analyses were performed on flue gas samples according to the EPA Level 1 protocol (Reference 3-2) as outlined in Appendix A. Volatile organic gas phase species having boiling points in the nominal C_1 to C_6 range of -160° to 100°C (-260° to 210°F) were measured by multiple analyses of flue gas samples using onsite gas chromatography. This procedure gives total volatile organics by boiling point range only. SASS samples were extracted with methylene chloride in a Soxhlet apparatus. Total semivolatile organics with boiling points in the nominal C_7 to C_{16} range of 100° to 300°C (210° to 570°F) were determined in the laboratory by total chromatographable organic (TCO) analyses of the organic module sorbent (XAD-2) and condensate sample extracts. Nonvolatile organic species having boiling points in the nominal $C_{16}+$ range of greater than 300°C (570°F) were determined by gravimetric (GRAV) analysis of SASS sample extracts, including filter and cyclone catches.

Infrared spectrometry (IR) was also performed on GRAV residues to identify organic functional groups present. In addition, gas chromatography/mass spectroscopy (GC/MS) analysis of total sample extracts was performed to identify specific polynuclear aromatic and other organic compounds (the semivolatile organic priority pollutants). A discussion of the analytical results follows.

3.4.1 C_1 to C_6, TCO and GRAV Analyses

Table 3-4 summarizes total organic emissions results from the TCO, GRAV, and onsite GC analyses. Approximately 90 percent of the organic emissions were in the C_1 to C_6 boiling point range and over half of those were in the C_3 boiling range. TCO emissions were below the detection limit for all

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TABLE 3-4. SUMMARY OF TOTAL ORGANIC EMISSIONS

	mg/dscm	ng/J	mg/kg fuel as fired
Volatile organic gases analyzed in the field by gas chromatography:			
C_1	1.2	0.72	14
C_2	0.5	0.30	5.7
C_3	2.8	1.68	32
C_4	0.5	0.30	5.7
C_5	ND	ND	ND
C_6	ND	ND	ND
Total C_1 to C_6	5.0	3.0	57
Semivolatile organics analyzed by TCO:			
XAD-2 cartridge	<0.01	<0.006	<0.11
Organic module condensate	<0.003	<0.002	<0.03
Total C_7 to C_{16}	<0.01	<0.006	<0.11
Nonvolatile organics analyzed by gravimetry:			
Probe wash	<0.2	<0.12	<2.3
10 + 3 µm cyclones	<0.2	<0.12	<2.3
Filter + 1 µm cyclone	0.4	0.24	4.5
XAD-2 cartridge	0.3	0.18	3.4
Organic module condensate	<0.1	<0.06	<1.1
Total C_{16+}	0.7	0.42	7.9
Total organics	5.7	3.4	65

ND -- Not detected

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samples analyzed, while the GRAV result accounted for the remainder of the organics emitted.

The organic emission results obtained for the XAD-2 extract have been compromised somewhat due to the use, in these tests, of XAD-2 resin which had been inadvertently contaminated by acetone between resin preparation and eventual use. Thus, several acetone solvent contaminants and acetone polymerization products (chiefly an acetone dimer), all of low molecular weight and in the TCO boiling point range, were introduced in the resin. This resulted in a high TCO blank for the XAD-2 resin. In an attempt to correct for the high blank, GC/MS analysis of the extracts was performed to identify and quantitate specific contaminant species in both the blank and sample extracts. Subtracting the amount of these contaminant species found in both sample and blank extracts from the TCO levels of each allowed definition of a corrected TCO value for the sample and the blank. These corrected values were used to calculate the TCO levels noted in Table 3-4. It should be noted that all contamination consisted of TCO boiling range compounds, so gravimetric results should be unaffected.

The total organic species emissions in the flue gas from this unit at 3.4 ng/J are lower than the range typical from wood-fired boilers (14 to 320 ng/J, Reference 3-3), and in fact are at the low end of the range noted in the other unit tested under the CMEA (65 mg/kg wood fired for this unit, 60 to 3,000 mg/kg for the other CMEA-tested unit, Reference 3-4).

The total TCO and GRAV organic content of all samples analyzed was sufficiently low, that further Level 1 analyses of the samples (i.e., liquid chromatography separation and low resolution mass spectrometry) was not warranted.

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3.4.2 IR Spectra of Total Sample Extracts

IR spectrometry was used to identify organic functional groups present in GRAV residue of the SASS sample extracts. The results of the IR analysis for the total extracts are summarized in Table 3-5. All spectra were relatively weak, consistent with the relatively low GRAV content of the extracts. The spectra of the 1 μm + filter and the XAD extracts suggest only the presence of aliphatic hydrocarbons. The spectra of the other samples were too weak to interpret.

3.4.3 Gas Chromatography/Mass Spectrometry Analysis of Total Sample Extracts

Capillary GC/MS analyses of the extracts of the flue gas samples collected by SASS were performed to detect and quantify specific POM and other organic compounds (the semivolatile organic priority pollutants). The

TABLE 3-5. SUMMARY OF IR SPECTRA OF TOTAL SAMPLE EXTRACTS

Sample	Wave number (cm^{-1})	Intensity	Possible assignment
Probe	--	--	No peaks
10 + 3μm	--	--	No peaks
1μm + filter	2,900	S	C-H stretch
Filter blank	--	--	No peaks
XAD-2	2,900	S	C-H stretch
	2,820	S	C-H stretch
OMC	--	--	No peaks

S = Strong

species sought in the analyses and their respective detection limits are listed in Table 3-6. The results of the GC/MS analyses are summarized in Table 3-7. The POM and other species listed were detected in measurable quantities only in the XAD extract, although phenol was also detected in the organic module condensate.

As shown in Table 3-7, five POM species were detected in the flue gas from the boiler test. Naphthalene was emitted in by far the greatest concentrations. Table 3-7 also notes the results obtained by the North Carolina DNR in simultaneous tests of this boiler (Reference 3-1). The sampling equipment employed by DNR was based on the modified EPA Method 5 technique developed by Battelle Columbus Laboratories (Reference 3-5). Collected samples were analyzed in the DNR tests by a capillary column GC/flame ionization detector (FID) technique. Table 3-7 shows remarkably good agreement in emission levels of the species analyzed in both test programs.

3.5 RADIONUCLIDE EMISSIONS

Radiometric activities of the composite particulate catch from the SASS train cyclones and filters are presented in Table 3-8. The sum of the alpha plus beta activities for the particulate, when converted to emission rate, corresponds to 820 pCi/kg fuel. By comparison, the radionuclide emissions (excluding radon) calculated for a coal-fuel powerplant range from 170 to 800 pCi/kg coal (Reference 3-6).

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TABLE 3-6. COMPOUNDS SOUGHT IN THE GC/MS ANALYSIS AND THEIR DETECTION LIMITS (ng/µl INJECTED)

Acid Compounds			
2,4,6-trichlorophenol	5	2-nitrophenol	5
p-chloro-m-cresol	5	4-nitrophenol	20
2-chlorophenol	5	2,4-dinitrophenol	20
2,4-dichlorophenol	5	4,6-dinitro-o-cresol	20
2,4-dimethylphenol	5	pentachlorophenol	5
		phenol	1

Base Neutral Compounds			
1,2,4-trichlorobenzene	1	benzo(c)phenanthrene	40
1,2-dichlorobenzene	1	bis(2-chloroethoxy)methane	1
1,2-diphenylhydrazine (as azobenzene)	1	bis(2-chloroethyl)ether	1
		bis(2-chloroisopropyl)ether	1
1,3-dichlorobenzene	1	bis(2-ethylhexyl)phthalate	1
1,4-dichlorobenzene	1	butyl benzyl phthalate	1
2,4-dinitrotoluene	1	chrysene	1
2,6-dinitrotoluene	1	di-n-butyl phthalate	1
2-chloronaphthalene	1	di-n-octyl phthalate	1
3,3'-dichlorobenzidine	5	dibenzo(a,h)anthracene	5
3-methyl cholanthrene	40	dibenzo(c,g)carbazole	40
4-bromophenyl phenyl ether	1	diethyl phthalate	1
4-chlorophenyl phenyl ether	1	dimethyl phthalate	1
7,12-dimethyl benz(a)anthracene	40	fluoranthene	1
N-nitrosodi-n-propylamine	5	fluorene	1
N-nitrosodimethylamine	NA	hexachlorobenzene	1
N-nitrosodiphenylamine	1	haxachlorobutadiene	1
acenaphthene	1	hexachlorocyclopentadiene	1
acenaphthylene	1	hexachloroethane	1
anthracene	1	indeno(1,2,3-cd)pyrene	5
benzo(ghi)perylene	5	isophorone	1
benzidine	20	naphthalene	1
benzo(b)fluoranthene	1	nitrobenzene	1
benzo(k)fluoranthene	1	perylene	40
benzo(a)anthracene	1	phenanthrene	1
benzo(a)pyrene	1	pyrene	1

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TABLE 3-7. POM AND OTHER ORGANIC SPECIES EMISSION SUMMARY

Compound	This study		DNR 1[a]		DNR 2[a]	
	µg/dscm	µg/kg fuel[b]	µg/dscm	µg/kg fuel[b]	µg/dscm	µg/kg fuel[b]
Acenaphthylene	0.30	3.4	NA	NA	NA	NA
Fluoranthene	0.08	0.9	ND	ND	ND	ND
Naphthalene	3.3	37.5	6.34	83.2	0.85	12.1
Phenanthrene	0.30	3.4	ND	ND	ND	ND
Pyrene	0.20	2.3	ND	ND	0.30	4.3
Phenol	0.38[c]	4.3	NA	NA	NA	NA
Detection limit	0.04	0.5	0.12	1.6	0.08	1.2

NA -- Compound not analyzed
ND -- Compound not detected above detection limit
[a]Reference 3-1
[b]Dry basis
[c]60 percent of phenol noted detected in the organic module condensate; all other results from XAD-2 extract only

TABLE 3-8. RADIOMETRIC ACTIVITY (pCi/g)[a] OF THE COMPOSITE SASS PARTICULATE

Sample	Alpha	Beta
Particulate composite	53.3 ± 37.2	328.1 ± 98.3

[a]The ± values are the 2 sigma Poisson standard deviation of the counting error

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SECTION 4

ENVIRONMENTAL ASSESSMENT

This section discusses the potential environmental impact of the wood-fired industrial boiler tested, and also discusses the results of the bioassay testing of the flue gas and bottom ash stream samples collected. The potential environmental impact is evaluated by comparing flue gas stream species concentrations to occupational exposure guidelines. These comparisons are made to rank species discharged for possible further consideration. Bioassay analyses were conducted as a more direct measure of the potential health and ecological effects of the effluent streams. Both these analyses are aimed at identifying potential problem areas and providing the basis for ranking pollutant species and discharge streams for further consideration.

4.1 EMISSIONS ASSESSMENT

To obtain a measure of the potential significance of the discharge streams analyzed in this test program, discharge stream concentrations were compared to indices which reflect potential for adverse health effects. For the flue gas discharge, the indices used for comparison were occupational exposure guidelines, specifically the time-weighted-average Threshold Limit Values (TLV's) defined by the American Conference of Governmental Industrial Hygienists (ACGIH) (Reference 4-1).

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The comparisons of the flue gas stream species concentrations to these occupational exposure guidelines are only performed to rank species emission levels with respect to potential for adverse effects. Conclusions concerning absolute risk associated with emissions are not, and should not, be drawn. These evaluations are only presented to place different species emitted into perspective and to rank them for further consideration.

Table 4-1 lists those pollutant species emitted in the flue gas at levels greater than 10 percent of their occupational exposure guideline. Emissions of NO_x (as NO_2) were almost two orders of magnitude higher than its (NO_2) occupational exposure guideline. CO, nickel, and phosphorus were emitted at levels exceeding their respective occupational exposure guidelines.

4.2 BIOASSAY RESULTS

Bioassay tests were performed on the organic sorbent (XAD-2) extracts, the particulate flyash collected by the SASS, and the bottom ash. Bioassay results reported here are for both health and ecological effects tests (Reference 4-2). The bioassay tests performed on the XAD-2 extracts were health effects tests only. These were:

- Ames assay, based on the property of Salmonella typhimurium mutants to revert due to exposure to various classes of mutagens
- Cytotoxicity assay (CHO) with mammalian cells in culture to measure cellular metabolic impairment and death resulting from exposure to soluble toxicants

In addition to the Ames test, health effects bioassay tests performed on the bottom ash and the particulate collected by the SASS included:

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TABLE 4-1. FLUE GAS SPECIES IN CONCENTRATIONS EXCEEDING 0.1 OF AN OCCUPATIONAL EXPOSURE LIMIT

Species	Flue gas concentration (µg/dscm)	Occupational exposure guidelines ($\mu g/m^3$)[a]
NO	2.56×10^5	6,000
CO	4.4×10^4 to 2.63×10^6	55,000
Nickel, Ni	190	100
Phosphorus, P	>120	100
Barium, Ba	>190	500
Lead, Pb	45	150
Chromium, Cr	15	50
Potassium, K	>400	2,000
Silver, Ag	1.9	10
Copper, Cu	32	200
Iron, Fe	>140	1,000

[a]Threshold Limit Value (Reference 4-1)

- The rabbit alveolar macrophage (RAM) cytotoxicity assay which gives a toxicity evaluation measured by the reduction in cell viability and adenosine triphosphate content of the cultures after several hours exposure to the test material
- The whole animal acute toxicity test in live rodents (WAT) to identify in vivo toxicity of samples

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Table 4-2 summarizes the results from the Ames, CHO, RAM, and WAT assays. The results suggest that the particulate and bottom ash were of nondetectable to low toxicity and mutagenicity. The XAD-2 extract showed moderate toxicity and mutagenicity.

The bottom ash was also tested for acute toxicity to freshwater invertebrates (Daphnia magna), freshwater fish (fathead minnow, Pimephales promelas) and freshwater algae (Selenastrum capricornutum). Table 4-3 summarizes the results of these tests. Results of these assays suggest that this sample was also of nondetectable to low toxicity to aquatic organisms.

4.3 SUMMARY

Comprehensive emission characterization tests were performed on a wood-waste-fired horizontal return tube firetube industrial boiler. Flue gas NO_x, CO, and particulate emissions were measured (SO_2 and SO_3 were sampled for, but not detected). In addition, flue gas emissions of 65 inorganic trace elements, total organics in three boiling point ranges, and POM's and selected other organic species (the semivolatile organic priority pollutants) were also measured. The boiler bottom ash was also analyzed for trace element composition.

CO emissions from the unit were quite variable and often quite high over the duration of the tests performed. Emissions ranged from about 100 to almost 10,000 ppm (dry, 3 percent O_2). The relatively high CO emission levels were a direct consequence of the relatively high excess air level at which the boiler operated. Stack gas O_2 ranged from 11 to 17 percent over the test duration, with an average level of about 13 percent (corresponding to 160 percent excess air). CO emissions were below 200 ppm (3 percent O_2) when O_2 was below 12 percent; however CO emissions increased to well over

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TABLE 4-2. BIOASSAY RESULTS (HEALTH EFFECTS)

Sample	Bioassay			
	Ames[a]	CHO[b]	RAM[b]	WAT[b]
Bottom ash	ND	NP	L/ND	ND
Composite particulate	ND	NP	L	NP
XAD-2 extract	M	M	NP	NP

ND -- Nondetectable
L -- Low
M -- Moderate
NP -- Assay not performed
[a]Mutagenicity test
[b]Toxicity test

TABLE 4-3. BOTTOM ASH BIOASSAY RESULTS (ECOLOGICAL EFFECTS)

Algal	Daphnia	Freshwater fish
L	L/ND	ND

L -- Low toxicity
ND -- Nondetectable toxicity

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1,000 ppm (3 percent O_2) when flue gas O_2 was above 15 percent. Corresponding boiler efficiency was a modest 65 percent.

NO_x emissions from the boiler, at about 300 ppm (dry, 3 percent O_2) equivalent to about 150 ng/J heat input, or about 3 g/kg wood, were relatively high for a wood-fired unit. However, the wood waste fired had a relatively high nitrogen content (for wood) at 0.18 percent nitrogen.

The total organic emissions from the boiler at 3.4 ng/J (65 mg/kg fuel) were relatively low for a wood-fired boiler. Almost 90 percent of the organic emissions were of volatile (boiling point less than 100°C) organics; the remaining 10 percent were of nonvolatile (boiling point greater than 300°C) organics. Several POM species were emitted in the flue gas at levels in the several µg/kg fuel range; naphthalene was emitted at greatest (almost 40 µg/kg) levels.

Compared to coal-fired industrial boilers in the same capacity range, NO_x emissions from the wood-fired unit are comparable, though at the low end of the 300 to 400 ppm range (3 percent O_2) typical of coal-fired stokers. SO_2 emissions from the wood-fired unit was lower than would be typical of a coal-fired unit, reflecting the very low sulfur content of wood.

Typical coal-fired boiler CO emissions are in the several hundred ppm or less range. Comparable emissions from the wood-fired unit tested were achievable, provided the excess air level was held below that corresponding to flue gas O_2 of 12 percent. However, over most of the wood-fired boiler test duration, CO emissions were higher.

Total semivolatile and nonvolatile (SASS train) organic emissions from this boiler were at the low end of the range typical for industrial wood

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firing. They were also at the low end of the range typical of industrial coal firing.

Emissions of several POM species (acenaphthylene, fluoranthene, phenanthrene, and pyrene) were measured in the 0.1 to 0.3 µg/dscm range, from the wood-fired unit tested. Naphthalene emissions were measured at 3.3 µg/dscm. Emissions of the same POM species, and in the same emission level range are not uncommon from industrial coal-fired sources, although even naphthalene is rarely emitted at levels greater than about 1 µg/dscm from such sources. The data suggest that POM emissions from the wood-fired industrial boiler may have been slightly higher than typical for other industrial fuels, but only slightly.

REFERENCES FOR SECTION 4

4-1. "Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1982," American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1982.

4-2. Brusick, D. J., and R. R. Young, "IERL-RTP Procedures Manual: Level 1 Environmental Assessment, Biological Tests," EPA-600/8-81-024, NTIS PB82-228966, October 1981.

APPENDIX A

SAMPLING AND ANALYSIS METHODS

Emission test equipment was provided by Acurex and the Office of Research and Development of EPA. Continuous monitoring analyses for O_2, CO, and NO_x emissions were provided by EPA personnel using an EPA mobile emission monitoring laboratory. Onsite equipment provided by Acurex included a sulfur oxides analysis train (controlled condensation equipment), the SASS train for particulate sizing and trace element and organic species collection, EPA Method 5 sampling train for total particulate emissions, and a gas chromatograph with a flame ionization detector (GC/FID) for gaseous (C_1 to C_6) hydrocarbon analyses. Source testing by Acurex and EPA was performed simultaneously with polycyclic organic matter (POM) emissions testing by the North Carolina Department of Natural Resources and Community Development (DNR). The equipment used by the DNR consisted of an EPA Method 5 sampling train modified for the collection of semivolatile organic species as described by Battelle-Columbus Laboratories (Reference A-1). SASS and Method 5 sampling was performed at the stack. The controlled condensation train, the continuous monitors, and the gas grab samples for C_1 to C_6 hydrocarbon analysis were taken at the boiler outlet, upstream of the unit's mechanical particulate collector. Wood fuel samples and bottom ash waste stream samples were taken by Acurex.

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The following sections briefly describe the equipment and sampling procedures used by Acurex and EPA during the source evaluation of the wood-fired industrial boiler.

A.1 CONTINUOUS MONITORING SYSTEM FOR GASEOUS EMISSIONS

The continuous monitors for flue gas analysis were furnished by EPA in their mobile sampling van. The gas samples were taken from the flue gas duct upstream of the induced draft (ID) fan. One sampling probe, located at the average centroid of the stack, was used in sampling the flue gas. Flue gas O_2, CO, and NO_x were measured using the instrumentation summarized in Table A-1; the calibration gases are listed in Table A-2. Figure A-1 illustrates the flue gas sampling system. The sampling probe is equipped with an in-stack filter for removal of particulate matter. The heated interface box, containing pneumatically operated valves, permitted the operator to transport calibration gas to the box and compressed air for "back-flushing" of the sampling probe and filter. The interface box is connected to the gas conditioning system by self-regulated heat-traced Teflon tubing. A two-stage condensation unit removes the water vapor from the sample prior to delivery to the distribution panel and analysis.

A.2 PARTICULATE EMISSIONS

Particulate mass emission tests were conducted in accordance with EPA Reference Methods 1 through 5. The Acurex High Volume Stack Sampler (HVSS), illustrated schematically in Figure A-2, was used in this program. A 1.52m (5-ft) heated stainless steel glass-lined probe was used to isokinetically extract samples from the stack. Probe temperature was maintained at 120°C (250°F) as required by EPA Method 5. A glass fiber 142-mm (5.59-in.) diameter filter was used to capture the particulates. The impinger train

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TABLE A-1. MOBILE LABORATORY INSTRUMENT COMPLEMENT

Analyzer	Manufacturer	Model number
Oxygen (O_2)	MSA	802
Oxides of nitrogen (NO_x)	TECO	10AR
Carbon monoxide (CO)	Horiba	PIR2000

TABLE A-2. CALIBRATION GASES

Standard	Diluent gas	Standard concentration
NO	Nitrogen	148 ppm
NO	Nitrogen	202 ppm
CO	Nitrogen	258 ppm
CO	Nitrogen	1,020 ppm
O_2	Nitrogen	11.1 percent
O_2	Compressed air	20.9 percent
Zero	Nitrogen	Zero gas

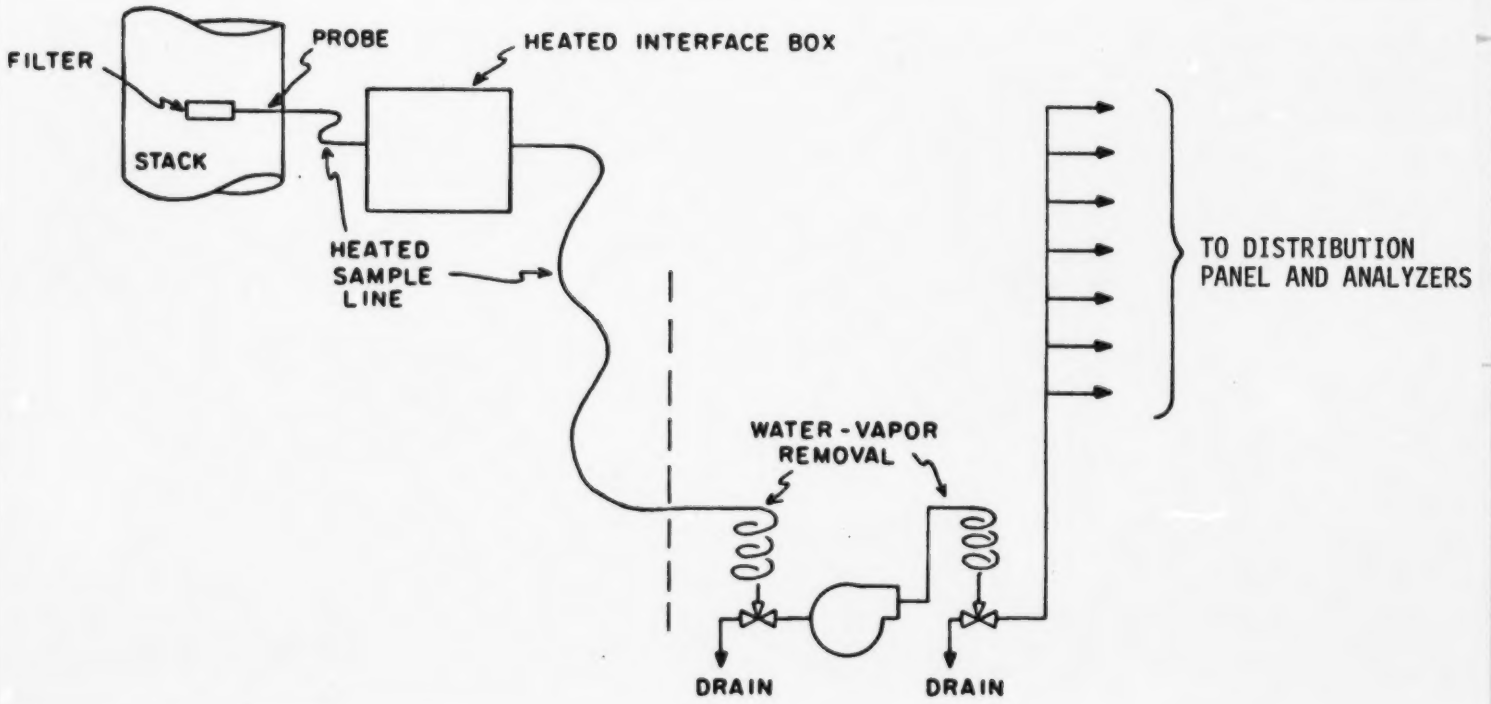
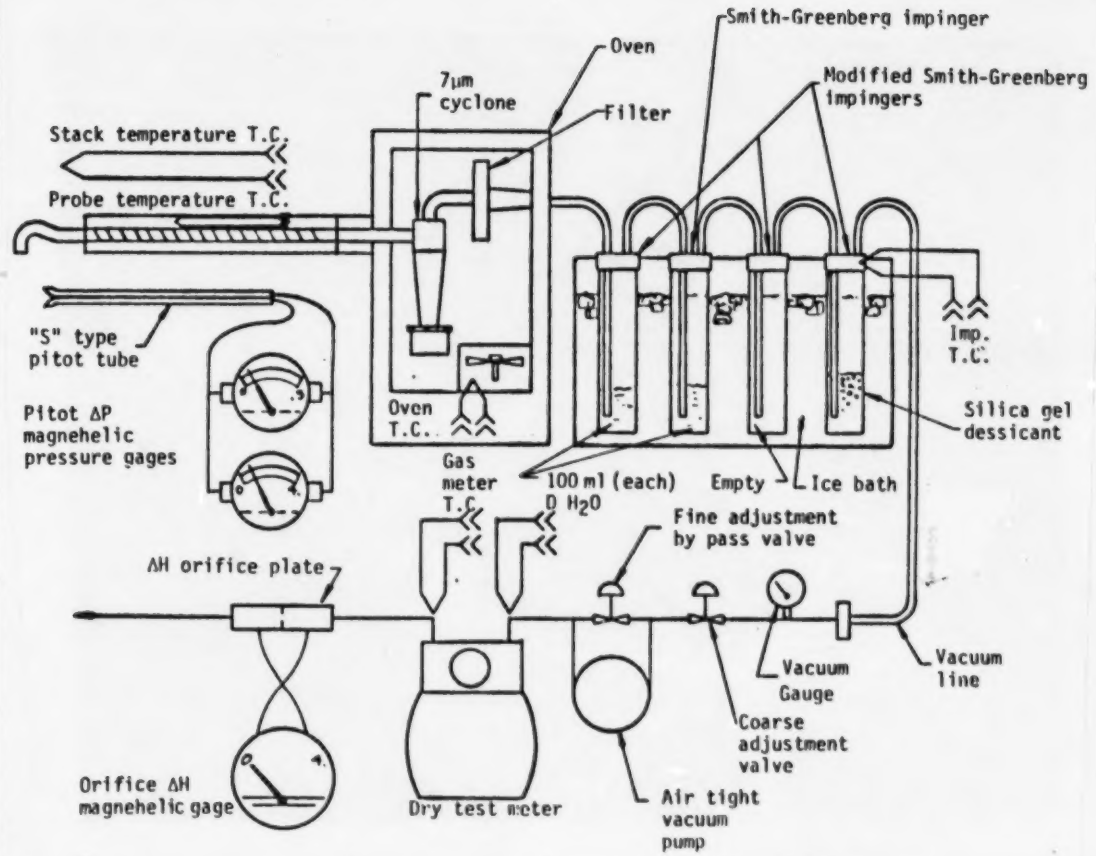


Figure A-1. Sample acquisition and conditioning system.



Note: T.C. = Thermocouple

Figure A-2. Particulate sampling train.

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consisted of four glass impingers equipped with Teflon caps and 316 stainless steel stems, collector tubes, and fittings. The first two impingers contained 100 ml of distilled water, the third was empty, and the fourth contained a known amount of silica gel. The control module is equipped with magnehelic gauges and digital thermocouple readouts, and a dry gas flowmeter for monitoring pressure and temperature in the stack and total gas sampled.

Sample collection took place in the uninsulated stack above the ID fan. The particulate tests were performed at 48 sampling points in accordance with EPA Method 1. Each test point was sampled for 2.5 min, hence a 120-min total sample time. Figure A-3 illustrates the Method 5 sample recovery protocol utilized to measure total particulate mass collected with the HVSS train. Solid particulate matter is defined as all particulate mass collected in the front half of the train; that is the filter, probe, and nozzle. Condensible particulate matter is obtained from gravimetric analyses of impinger liquids and impinger rinses.

A.3 SULFUR EMISSIONS

Sulfur emissions (SO_2 and SO_3) were measured using the controlled condensation system illustrated in Figure A-4. This sampling system, designed primarily to measure vapor phase concentration of SO_3 as H_2SO_4, consists of a heated quartz probe, a Goksoyr/Ross condenser (condensation coil), impingers, a pump, and a dry gas test meter. Using the Goksoyr/Ross condenser, the gas is cooled to the dew point where SO_3 condenses as H_2SO_4. SO_2 interference is prevented by maintaining the temperature of the gas above the water dew point. Sulfur dioxide is collected in a 3 percent hydrogen peroxide solution. A more detailed discussion of the controlled condensation sampling system is given in Reference A-2.

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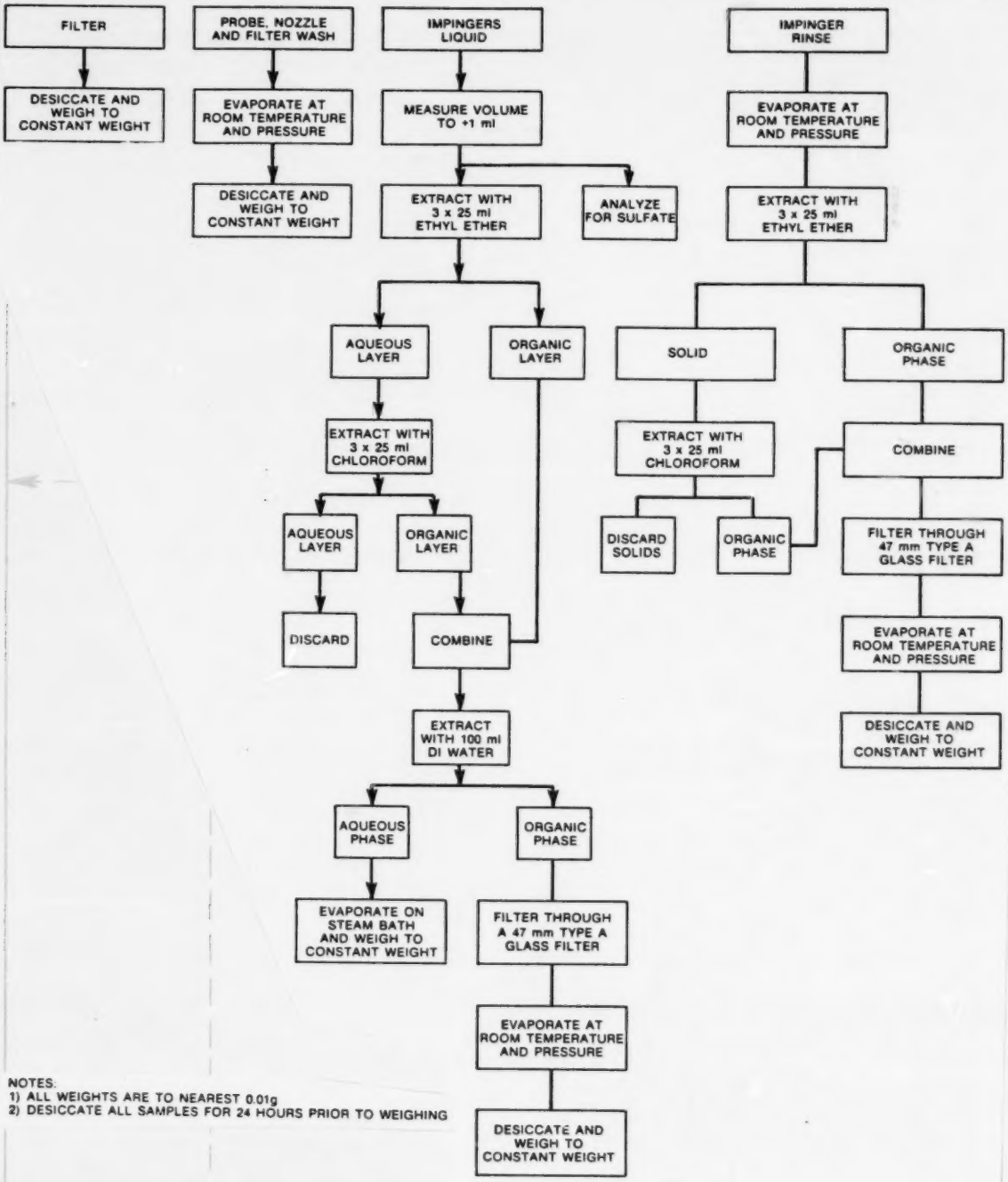
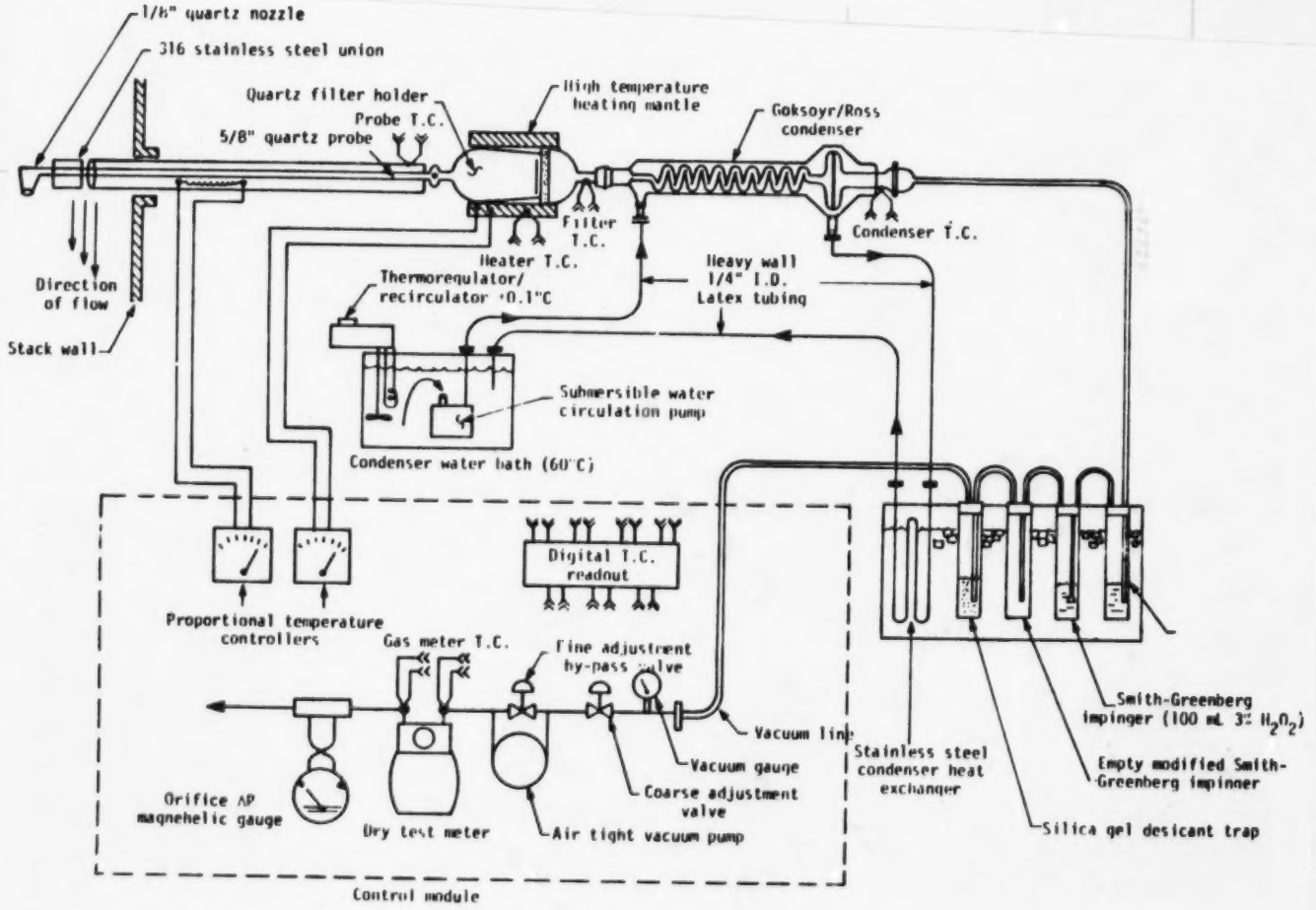

FILTER
PROBE, NOZZLE AND FILTER WASH
IMPINGERS LIQUID
IMPINGER RINSE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
MEASURE VOLUME TO +1 ml
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
EXTRACT WITH 3 x 25 ml ETHYL ETHER
ANALYZE FOR SULFATE
EXTRACT WITH 3 x 25 ml ETHYL ETHER
AQUEOUS LAYER
ORGANIC LAYER
SOLID
ORGANIC PHASE
EXTRACT WITH 3 x 25 ml CHLOROFORM
EXTRACT WITH 3 x 25 ml CHLOROFORM
COMBINE
AQUEOUS LAYER
ORGANIC LAYER
DISCARD SOLIDS
ORGANIC PHASE
FILTER THROUGH 47 mm TYPE A GLASS FILTER
DISCARD
COMBINE
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
EXTRACT WITH 100 ml DI WATER
DESICCATE AND WEIGH TO CONSTANT WEIGHT
AQUEOUS PHASE
ORGANIC PHASE
EVAPORATE ON STEAM BATH AND WEIGH TO CONSTANT WEIGHT
FILTER THROUGH A 47 mm TYPE A GLASS FILTER
EVAPORATE AT ROOM TEMPERATURE AND PRESSURE
DESICCATE AND WEIGH TO CONSTANT WEIGHT
NOTES:
1) ALL WEIGHTS ARE TO NEAREST 0.01g
2) DESICCATE ALL SAMPLES FOR 24 HOURS PRIOR TO WEIGHING

Figure A-3. Sample analysis scheme for particulate sampling train.



Note: T.C. = Thermocouple

Figure A-4. Controlled condensation system.

Both SO_2 and SO_3 (as H_2SO_4) were measured by titration with a 0.02 N NaOH using bromphenol blue and barium/thorin as the indicators. Results of the titration with bromphenol blue indicator were considered questionable due to pH imbalances in the blanks and samples. Most of the samples analyzed required the addition of acid to swing the indicator color to yellow for titration to a basic end point. Although SO_2 and SO_3 analyses using this indicator showed concentrations in the range of 3 to 8 ppm respectively, the results were considered of questionable validity because of problems associated with pipette errors and varying end points.

The results of the barium/thorin titration seemed to be much more definitive. For the most part end points were easily determined and the results consistent. Using this titration method the analysis indicated that there was no detectable oxidized sulfur species in the sampled flue gas stream.

A.4 TRACE ELEMENTS AND ORGANIC EMISSIONS

Emissions of inorganic trace elements and organic compounds were sampled with the source assessment sampling system (SASS). Designed for Level 1 environmental assessment (Reference A-3), the SASS collects large quantities of gas and solid samples required for subsequent analyses of inorganic and organic emissions as well as particle size measurement.

The SASS, illustrated in Figure A-5, is generally similar to the system utilized for total particulate mass emission tests (HVSS) with the exception of:

- Particulate cyclones heated in the oven with the filter to 230°C (450°F)

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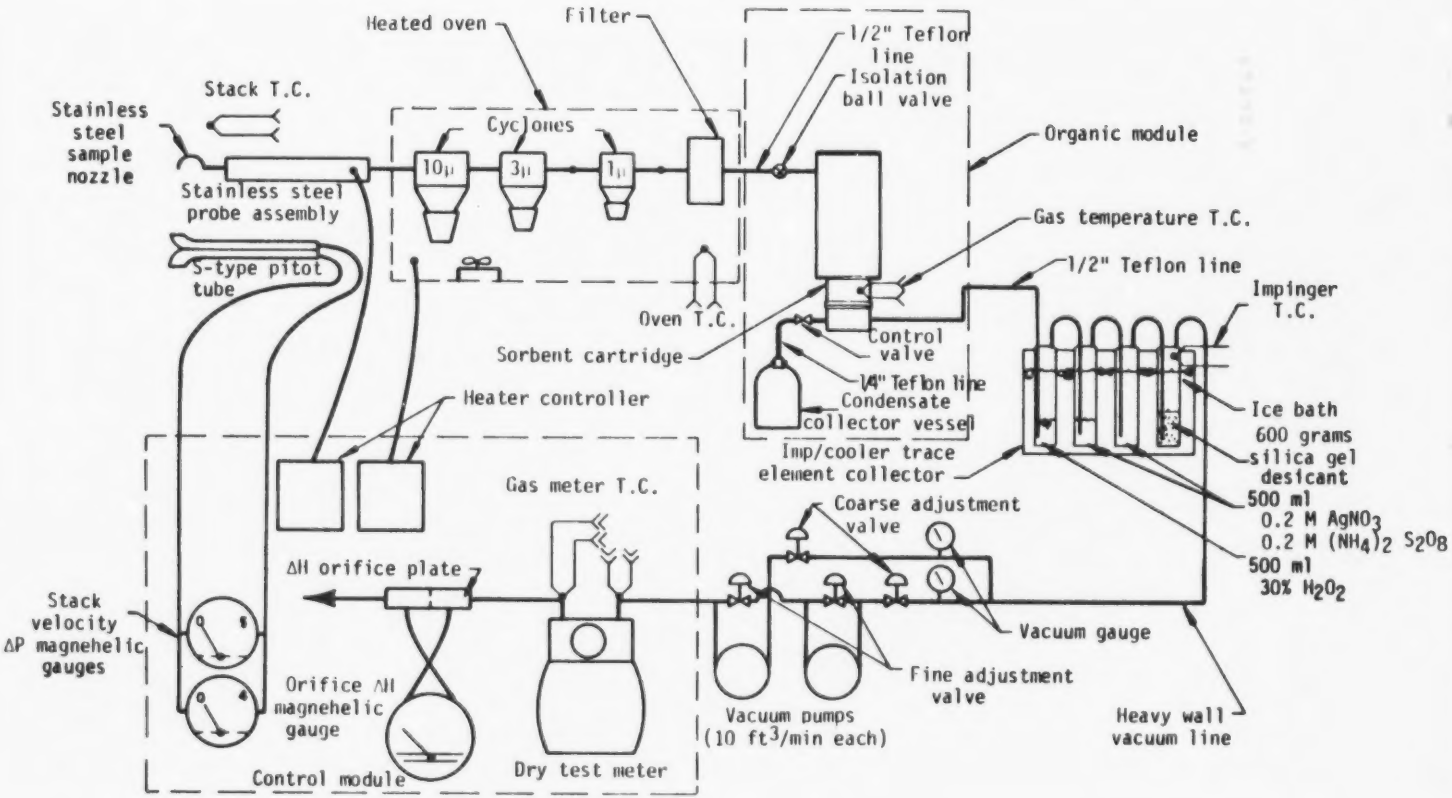


Note: T.C. = Thermocouple

Figure A-5. Source assessment sampling system train schematic.

- The addition of a gas cooler and organic sampling module
- The addition of necessary vacuum pumps

Schematics outlining the sampling and analytical procedures using the SASS equipment are presented in Figures A-6 and A-7. The following briefly describe analytical procedures used in measuring stack outlet trace elements and organic emissions.

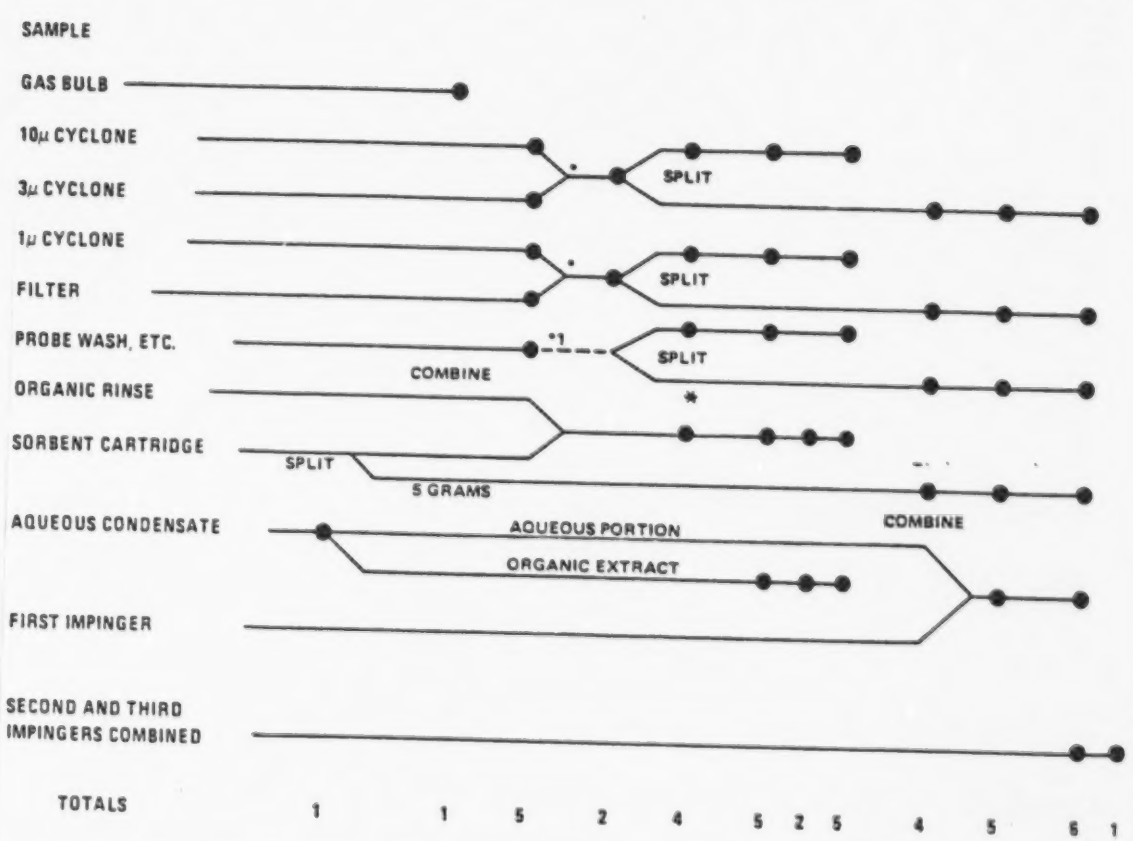
Inorganic analyses of solid and liquid samples from the SASS train were performed with spark source mass spectroscopy (SSMS) for most of the trace elements. Atomic Absorption Spectrometry (AAS) was used for analyses of volatile mercury (Hg), antimony (Sb), and arsenic (As).

Quantitative information on total organic emissions was obtained by gas chromatography for total chromatographable organics (TCO) and by gravimetry (GRAV) of particulate, sorbent module (XAD-2), and condensate trap organic extracts. Infrared spectroscopy (IR) was used for identification of organic functional groups and gas chromatography/mass spectroscopy (GC/MS) was used to quantitate POM and other organic species in extract samples. Figure A-8 illustrates the organic analysis methodology followed during the current program.

A.5 C_1 TO C_6 HYDROCARBON SAMPLING AND ANALYSIS

Samples of flue gas were collected for C_1 to C_6 hydrocarbon analysis using a grab sampling procedure. Flue gas was extracted from upstream of the induced draft fan at the same location used for the controlled condensation sampling system.

Samples for gaseous hydrocarbon analysis were collected using the apparatus illustrated in Figure A-9. The equipment consisted of a heated, 0.64-cm (1/4-in.) OD pyrex-lined, stainless-steel probe fitted with a glass



* If required, sample should be set aside for biological analysis at this point.

[1] This step is required to define the total mass of particulate catch. If the sample exceeds 10% of the total cyclone and filter sample weight proceed to analysis. If the sample is less than 10% of the catch, hold in reserve.

Figure A-6. Flue gas analysis protocol for SASS samples.

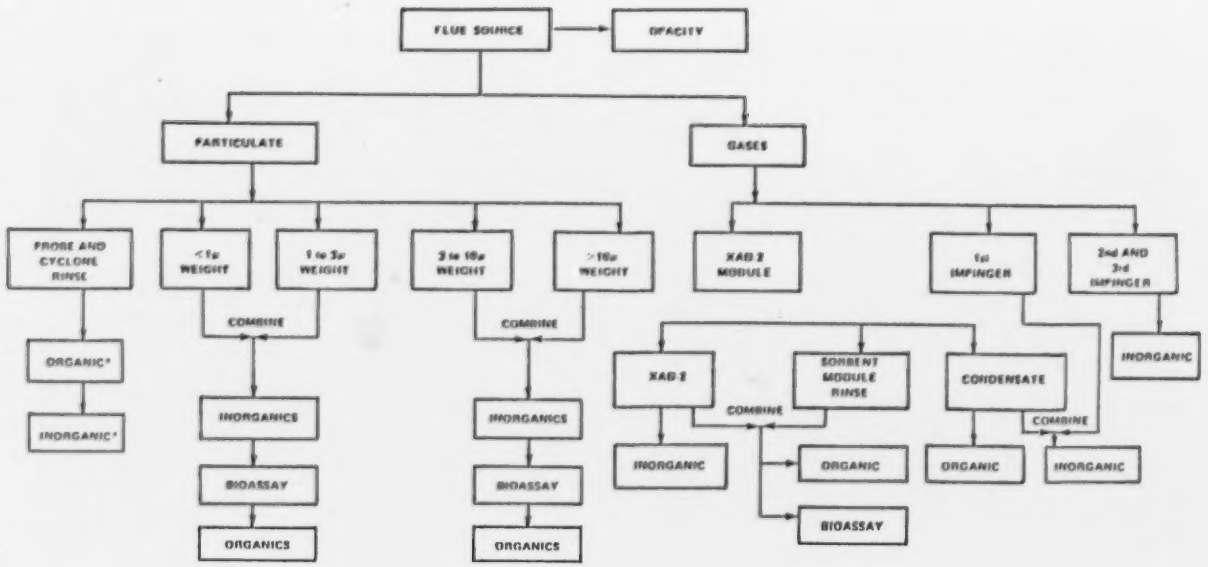


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Figure A-7. Flue gas analysis protocol.

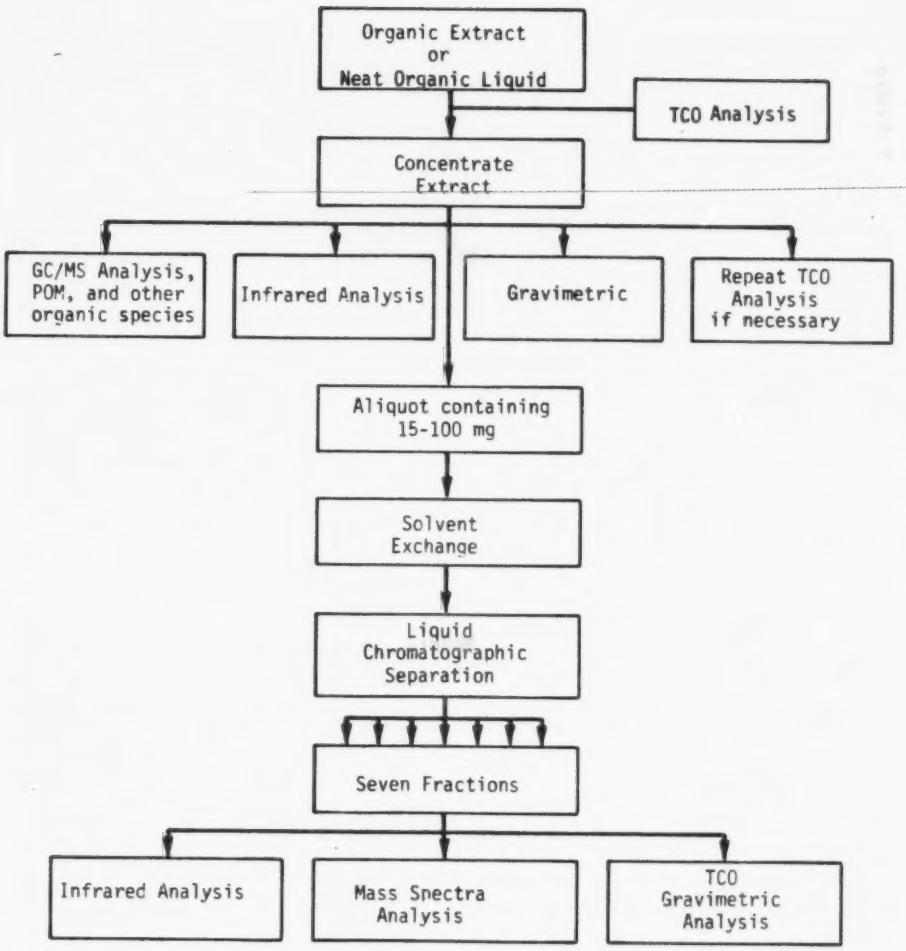
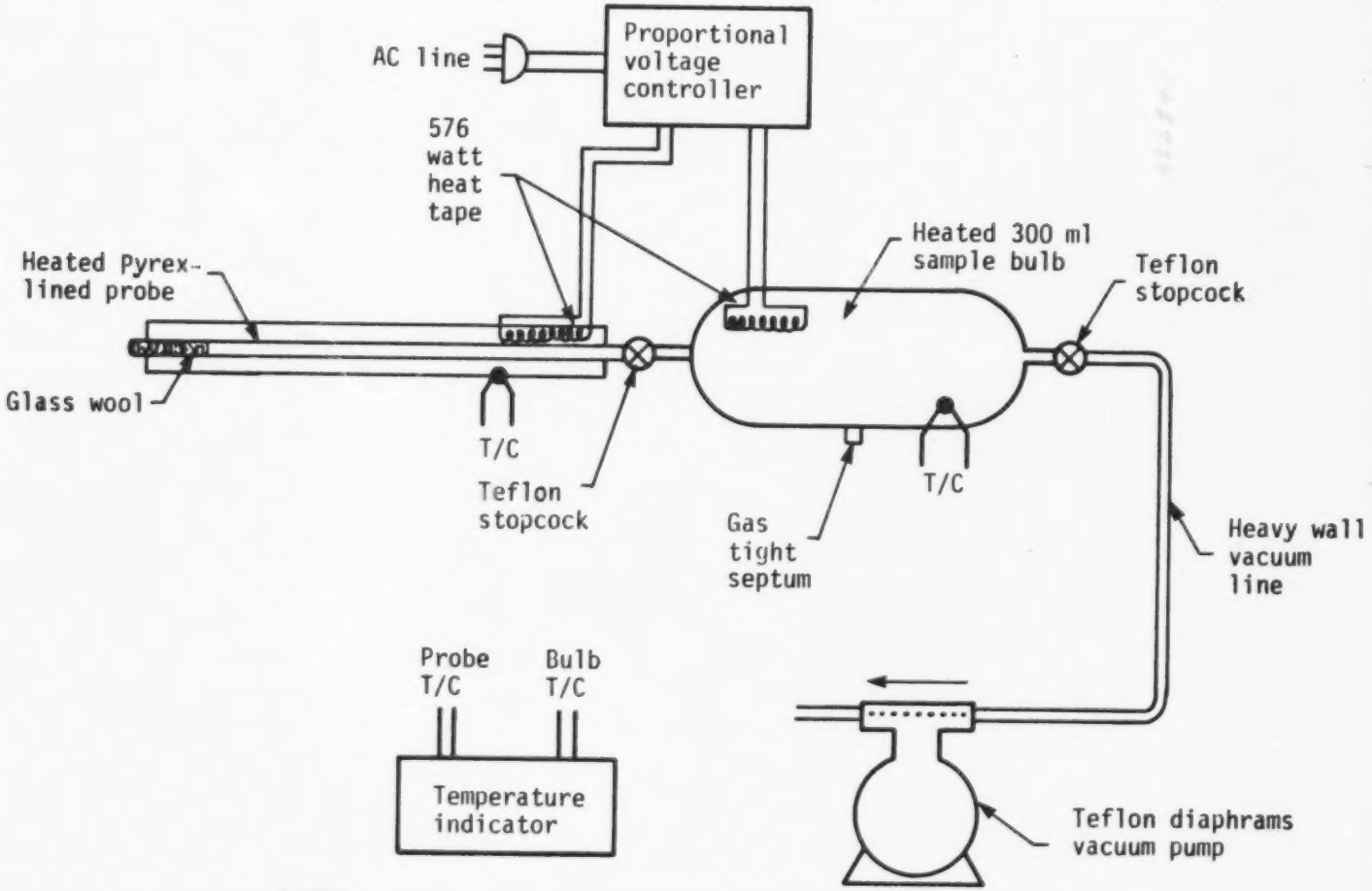


Figure A-8. Organic analysis methodology.



Note: T/C = Thermocouple

Figure A-9. Diagram of C_1 to C_6 hydrocarbon sampling system.

wool filter at the probe inlet. The outlet of the probe was directly attached to a 300-ml pyrex sampling bulb. The bulb was equipped with Teflon gas-tight stopcocks at each end and a septum port for sample removal. The sampling bulb was insulated with heat tape powered by a varying voltage controller. The heating jacket kept the sample gas above the dew point to minimize sample loss due to water condensation.

Prior to sampling, the gas bulb was purged with stack gas for 3 min and then sealed. The trapped flue gas was then analyzed onsite with a Carle 8500 gas chromatograph (GC) equipped with a flame ionization detector. Table A-3 lists the design specifications of the Carle GC. A 1.85-m (6-ft) long, 0.32-cm (1/8-in.) diameter stainless-steel column packed with Porapak Q 60/80 mesh was used to separate the hydrocarbons into their respective components (C_1 to C_6). The GC was calibrated with repeated injections of a standard gas containing C_1 to C_6 hydrocarbons (each having a concentration of 15 ppm). The chromatographic responses for the standards and the samples were recorded on a Hewlett-Packard Model 3390A reporting integrator.

A.6 FUEL AND BOTTOM ASH SAMPLING

Wood fuel samples were collected at the outlet of the storage silos. Multiple samples were taken over the duration of each test. The final sample used in proximate and ultimate analyses and inorganic trace element analysis represented a composite of all samples taken. Bottom ash was collected from the furnace downstream of the bridgewall, the day after the test.

TABLE A-3. GAS CHROMATOGRAPH SPECIFICATIONS
(CARLE INSTRUMENTS, INC. MODEL 8500)

Sensitivity:	5×10^{-12} A for 1 mV output
Suppression range:	10^{-9} A
Noise:	0.5 percent peak to peak on most sensitive range
Time constant:	100 ms on all ranges except "1" range which is 200 ms
Gas required:	Carrier gas (helium) Combustion air Fuel gas (hydrogen)

REFERENCES FOR APPENDIX A

A-1. Jones, P. W., et al., "Measurement of Polycyclic Organic Material and Other Hazardous Organic Compounds in Stack Gases -- State of the Art," EPA-600/2-77-202, NTIS PB274013, October 1977.

A-2. Maddalone, R., and N. Gainer, "Process Measurement Procedures: H_2SO_4 Emissions," EPA-600/7-79-156, NTIS PB80-115959, July 1979.

A-3. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, NTIS PB293795, October 1978.

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APPENDIX B

TRACE ELEMENT CONCENTRATIONS

The following tables present sample trace element analysis results and trace element discharge streams concentrations. The table labeled "ppm" represents element analysis results (microgram per gram) for each sample analyzed. Compositions for the wood fuel, the bottom ash, and all SASS train samples (probe wash, 10 and 3 μm particulate, filter and 1 μm particulate, XAD-2 resin, first impinger, and second and third impingers) are noted.

The table labeled "mass/heat input" gives calculated trace element concentrations in units of (microgram per dry standard cubic meter) heat input for the fuel and all SASS train samples. The column labeled "boiler outlet" represents the appropriate sum of SASS train samples.

The table labeled "concentration" gives the calculated flue gas concentration (μg/dscm) of each element corresponding to each SASS train sample, and the SASS train sum (labeled "boiler outlet").

Symbols appearing in the tables:

DSCM	Dry standard cubic meter at 1 atm and 20°C
MCG	Microgram
PPM	Parts per million by weight
NG/J	Nanogram per Joule heat input
<	Less than
>	Greater than

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N Element not analyzed

U Unable to determine

Trace elements having concentrations less than the detectable limit or having a blank value greater than the sample value were given an arbitrary concentration of zero. Values in the form A < x < B were determined by letting elements reported as less than a certain concentration be represented by a concentration of zero for the low value and the reported (less than) concentration as the high value.

Detectability limits for the various samples were the following:

- Particulate (cyclones and filter) <0.1 μg/g
- XAD-2 <0.1 μg/g
- Impinger and organic module concentrate <0.001 μg/ml
- Wood <0.01 μg/g
- Bottom ash <0.1 μg/g

Standard conditions: 20°C (68°F) and 1 atm. One molecular weight of an ideal gas occupies 24.04 l at standard conditions.

Fuel feedrate	kg/s (lb/hr)	0.514 (4,070)
Heat input	MW (million Btu/hr)	9.71 (33.1)
Stack gas flowrate	dscm/s (dscfm)	5.84 (12,380)
Gas collected (SASS)	dscm (dscf)	28.78 (1,016)
Stack gas molecular weight	dry wet	29.77 29.08
Water in stack gas	(percent)	5.54
O_2	(percent dry)	13.1

BURLINGTON
BASELINE
PPM

ELEMENT	FUEL: WOOD PPM	BOTTOM ASH	10U + 3U
ALUMINUM	.200E+01	>.100E+04	>.100E+04
ANTIMONY	N.000E+00	N.000E+00	N.000E+00
ARSENIC	N.000E+00	N.000E+00	N.000E+00
BARIUM	.210E+02	>.100E+04	>.100E+04
BERYLLIUM	<.100E-01	.200E+00	.200E+00
BISMUTH	.000E+00	.000E+00	.600E+00
BORON	.200E+00	.280E+03	.570E+03
BROMINE	.200E+00	.400E+01	.210E+02
CADMIUM	.900E-01	.800E+00	.170E+02
CALCIUM	>.100E+03	>.100E+04	>.100E+04
CERIUM	.600E+00	.660E+02	.240E+03
CESIUM	<.100E-01	.700E+00	.100E+01
CHLORINE	.220E+02	.110E+03	>.100E+04
CHROMIUM	.300E-01	.520E+02	.100E+03
COBALT	.900E-01	.300E+01	.170E+02
COPPER	.200E+01	.610E+02	.170E+03
DYSPROSIUM	.000E+00	.200E+01	.400E+01
ERBIUM	.000E+00	.400E+00	.200E+01
EUROPIUM	<.100E-01	.100E+01	.200E+01
FLUORINE	.400E+00	.160E+03	.140E+03
GADOLINIUM	.100E-01	.200E+01	.500E+01
GALLIUM	.400E-01	.700E+01	.700E+01
GERMANIUM	.100E-01	.300E+00	.200E+01
HAFNIUM	.000E+00	.300E+00	.000E+00
HOLMIUM	.000E+00	.100E+01	.300E+01
IODINE	.300E-01	.500E+00	.300E+01
IRON	.120E+02	>.100E+04	>.100E+04
LANTHANUM	.500E+00	.120E+03	.240E+03
LEAD	.200E+00	.820E+02	.170E+03
LITHIUM	.700E-01	.650E+02	.300E+01
LUTETIUM	.000E+00	<.100E+00	.400E+00
MAGNESIUM	>.100E+03	>.100E+04	>.100E+04
MANGANESE	.170E+02	>.460E+03	>.920E+03
MERCURY	<.500E-01	<.500E-01	<.102E+01
MOLYBDENUM	.200E-01	.130E+02	.200E+02
NEODYMIUM	.200E-01	.220E+02	.250E+02
NICKEL	.200E+00	.750E+02	.300E+03
NIOBIUM	.100E-01	.100E+01	.200E+01
PHOSPHORUS	.570E+02	>.100E+04	>.100E+04
PLATINUM	.000E+00	.000E+00	.000E+00
POTASSIUM	>.620E+02	>.100E+04	>.100E+04
PRASEODYMIUM	.600E-01	.100E+02	.210E+02
RUBIDUM	.400E+00	.280E+03	.520E+03
SAMARIUM	.500E-01	.900E+01	.190E+02
SCANDIUM	<.100E-01	.100E+01	<.100E-00
SELENIUM	.600E-01	.200E+01	.280E+02
SILICON	.170E+02	>.100E+04	>.100E+04
SILVER	<.100E-01	.000E+00	.170E+02
SODIUM	>.130E+02	>.100E+04	>.100E+04
STRONTIUM	.300E+01	>.100E+04	>.100E+04
SULFUR	.600E+01	>.100E+04	>.100E+04
TANTALUM	.000E+00	.000E-00	.300E+01
TELLURIUM	<.100E-01	.300E+00	.700E+00
TERBIUM	<.100E-01	.900E+00	.200E+01
THALLIUM	.000E+00	.000E+00	.600E+00
THORIUM	.000E+00	.900E+00	.100E+01
THULIUM	.000E+00	<.100E+00	.300E+00
TIN	.200E-01	.200E+01	.800E+01
TITANIUM	.300E+01	>.100E+04	>.100E+04
TUNGSTEN	.000E+00	.250E+02	.890E+02
URANIUM	.000E+00	.400E+00	<.600E+00
VANADIUM	.400E-01	.150E+02	.900E+01
YTTERBIUM	.000E+00	.500E+00	.200E+01
YTTRIUM	.700E-01	.150E+02	.400E+02
ZINC	.300E+01	.240E+03	>.100E+04
ZIRCONIUM	.300E+00	.700E+01	.150E+02

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TYPING GUIDE SHEET

BURLINGTON
BASELINE

PPM

ELEMENT	1U + FILTER	PROBE WASH	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS
ALUMINUM	U.000E+00	>.100E+04	.100E+01	.000E+00	N.000E+00
ANTIMONY	N.000E+00	N.000E+00	N.000E+00	N.000E+00	<.110E-02
ARSENIC	N.000E+00	N.000E+00	<.110E-02	N.000E+00	N.000E+00
BARIUM	.102E+04	>.100E+04	.000E+00	.000E+00	N.000E+00
BERYLLIUM	.000E+00	<.100E+00	.000E+00	.000E+00	N.000E+00
BISMUTH	<.520E+00	.100E+00	.000E+00	.000E+00	N.000E+00
BORON	.000E+00	.310E+03	.000E+00	.000E+00	N.000E+00
BROMINE	.000E+00	.110E+02	.000E+00	.000E+00	N.000E+00
CADMIUM	.104E+01	.100E+02	.000E+00	.000E+00	N.000E+00
CALCIUM	>.208E+04	>.100E+04	.610E+02	U.000E+00	N.000E+00
CERIUM	.468E+01	.170E+03	.000E+00	.000E+00	N.000E+00
CESIUM	<.520E+00	.900E+00	.000E+00	<.100E-02	N.000E+00
CHLORINE	.153E+04	>.100E+04	.320E+02	.250E+00	N.000E+00
CHROMIUM	.468E+01	.120E+03	.100E+01	.250E-01	N.000E+00
COBALT	.520E+00	.100E+02	.000E+00	.000E+00	N.000E+00
COPPER	.145E+02	.780E+02	.200E+01	.197E+00	N.000E+00
DYSPROSIUM	<.520E+00	.600E+01	.000E+00	.000E+00	N.000E+00
ERBIUM	<.520E+00	.100E+01	.000E+00	.000E+00	N.000E+00
EUROPIUM	<.520E+00	.300E+01	.000E+00	.000E+00	N.000E+00
FLUORINE	.208E+03	>.100E+04	.400E+00	.000E+00	N.000E+00
GADOLINIUM	<.520E+00	.400E+01	.000E+00	.000E+00	N.000E+00
GALLIUM	.000E+00	.400E+01	.000E+00	.200E-01	N.000E+00
GERMANIUM	.520E+00	.100E+01	.000E+00	.000E+00	N.000E+00
HAFNIUM	<.520E+00	.800E+00	.000E+00	.000E+00	N.000E+00
HOLMIUM	<.520E+00	.200E+01	.000E+00	.000E+00	N.000E+00
IODINE	.000E+00	.200E+01	.000E+00	.100E-02	N.000E+00
IRON	.676E+02	>.100E+04	.130E+02	.000E+00	N.000E+00
LANTHANUM	.468E+01	.140E+03	.000E+00	.000E+00	N.000E+00
LEAD	.259E+03	.240E+03	.000E+00	.200E-02	N.000E+00
LITHIUM	.104E+01	.100E+01	.000E+00	.000E+00	N.000E+00
LUTETIUM	<.520E+00	.300E+00	.000E+00	.000E+00	N.000E+00
MAGNESIUM	.000E+00	>.100E+04	.000E+00	.200E-01	N.000E+00
MANGANESE	>.154E+03	>.100E+04	.000E+00	.100E-01	N.000E+00
MERCURY	<.431E+00	<.886E+00	<.440E-01	<.960E-03	<.110E-02
MOLYBDENUM	.260E+01	.150E+02	.000E+00	.000E+00	N.000E+00
NEODYMIUM	.156E+01	.140E+02	.000E+00	.000E+00	N.000E+00
NICKEL	.135E+02	.120E+03	.350E+02	.180E+00	N.000E+00
NIOBIUM	.104E+01	.200E+01	.000E+00	.200E-02	N.000E+00
PHOSPHORUS	>.312E+03	>.100E+04	.260E+01	.000E+00	N.000E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00	N.000E+00
POTASSIUM	>.520E+02	>.100E+04	.720E+02	.000E+00	N.000E+00
PRASEODYMIUM	.000E+00	.270E+02	.000E+00	.000E+00	N.000E+00
RUBIDUM	.514E+02	.110E+03	.000E+00	.300E-02	N.000E+00
SAMARIUM	.520E+00	.120E+02	.000E+00	.000E+00	N.000E+00
SCANDIUM	.000E+00	.800E+00	.000E+00	.000E+00	N.000E+00
SELENIUM	.520E+00	.700E+01	.000E+00	<.300E-01	N.000E+00
SILICON	U.000E+00	>.100E+04	.450E+02	.000E+00	N.000E+00
SILVER	.260E+01	.240E+02	.000E+00	.200E-02	N.000E+00
SODIUM	U.000E+00	>.100E+04	.000E+00	U.000E+00	N.000E+00
STRONTIUM	.478E+02	.930E+03	.000E+00	.000E+00	N.000E+00
SULFUR	>.000E+00	>.100E+04	.500E+01	>.793E+01	N.000E+00
TANTALUM	<.520E+00	<.100E+01	.000E+00	.000E+00	N.000E+00
TELLURIUM	<.520E+00	.000E+00	.000E+00	.400E-02	N.000E+00
TERBIUM	<.520E+00	.100E+01	.000E+00	.000E+00	N.000E+00
THALLIUM	.000E+00	.310E+02	.000E+00	.000E+00	N.000E+00
THORIUM	<.520E+00	.100E+01	.000E+00	.000E+00	N.000E+00
THULIUM	<.520E+00	.400E+00	.000E+00	.000E+00	N.000E+00
TIN	.104E+01	.500E+01	.000E+00	.000E+00	N.000E+00
TITANIUM	.000E+00	>.100E+04	.000E+00	.000E+00	N.000E+00
TUNGSTEN	.208E+02	.400E+01	.000E+00	.000E+00	N.000E+00
URANIUM	<.520E+00	<.900E+00	.000E+00	.000E+00	N.000E+00
VANADIUM	.000E+00	.250E+02	.000E+00	.100E-02	N.000E+00
YTTERBIUM	<.520E+00	.100E+01	.000E+00	.000E+00	N.000E+00
YTTRIUM	.520E+00	.190E+02	.000E+00	.000E+00	N.000E+00
ZINC	.516E+03	>.100E+04	.000E+00	.780E+00	N.000E+00
ZIRCONIUM	.000E+00	.800E+01	.100E+01	.000E+00	N.000E+00

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MASS/HEAT INPUT — BASELINE — NG/J

ELEMENT	FUEL	WOOD	10U + 3U	1U + FILTER
ALUMINUM		.106E+00	> .236E-01	U .000E+00
ANTIMONY	N	.000E+00	N .000E+00	N .000E+00
ARSENIC	N	.000E+00	N .000E+00	N .000E+00
BARIUM		.111E+01	> .236E-01	.717E-01
BERYLLIUM	<	.529E-03	.473E-05	.000E+00
BISMUTH		.000E+00	.142E-04	< .364E-04
BORON		.106E-01	.135E-01	.000E+00
BROMINE		.106E-01	.496E-03	.000E+00
CADMIUM		.476E-02	.402E-03	.728E-04
CALCIUM	>	.529E+01	> .236E-01	> .146E+00
CERIUM		.318E-01	.567E-02	.328E-03
CESIUM	<	.529E-03	.236E-04	< .364E-04
CHLORINE		.116E+01	> .236E-01	.107E+00
CHROMIUM		.159E-02	.236E-02	.328E-03
COBALT		.476E-02	.402E-03	.364E-04
COPPER		.106E+00	.402E-02	.102E-02
DYSPROSIUM		.000E+00	.945E-04	< .364E-04
ERBIUM		.000E+00	.473E-04	< .364E-04
EUROPIUM	<	.529E-03	.473E-04	< .364E-04
FLUORINE		.212E-01	.331E-02	.146E-01
GADOLINIUM		.529E-03	.118E-03	< .364E-04
GALLIUM		.212E-02	.165E-03	.000E+00
GERMANIUM		.529E-03	.473E-04	.364E-04
HAFNIUM		.000E+00	.000E+00	< .364E-04
HOLMIUM		.000E+00	.709E-04	< .364E-04
IODINE		.159E-02	.709E-04	.000E+00
IRON		.635E+00	> .236E-01	.473E-02
LANTHANUM		.265E-01	.567E-02	.328E-03
LEAD		.106E-01	.402E-02	.181E-01
LITHIUM		.371E-02	.709E-04	.728E-04
LUTETIUM		.000E+00	.945E-05	< .364E-04
MAGNESIUM	>	.529E+01	> .236E-01	.000E+00
MANGANESE		.900E+00	> .217E-01	> .108E-01
MERCURY	<	.265E-02	< .241E-04	< .302E-04
MOLYBDENUM		.106E-02	.473E-03	.182E-03
NEODYMIUM		.106E-02	.591E-03	.109E-03
NICKEL		.106E-01	.709E-02	.947E-03
NIOBIUM		.529E-03	.473E-04	.728E-04
PHOSPHORUS		.302E+01	> .236E-01	> .218E-01
PLATINUM		.000E+00	.000E+00	.000E+00
POTASSIUM	>	.328E+01	> .236E-01	> .384E-02
PRASEODYMIUM		.318E-02	.496E-03	.000E+00
RUBIDUM		.212E-01	.123E-01	.360E-02
SAMARIUM		.265E-02	.449E-03	.364E-04
SCANDIUM	<	.529E-03	< .236E-05	.000E+00
SELENIUM		.318E-02	.662E-03	.384E-04
SILICON		.900E+00	> .236E-01	U .000E+00
SILVER	<	.529E-03	.402E-03	.182E-03
SODIUM	>	.688E+00	> .236E-01	U .000E+00
STRONTIUM		.159E+00	> .236E-01	.335E-02
SULFUR		.318E+00	> .236E-01	> .000E+00
TANTALUM		.000E+00	.709E-04	< .364E-04
TELLURIUM	<	.529E-03	.165E-04	< .364E-04
TERBIUM	<	.529E-03	.473E-04	< .364E-04
THALLIUM		.000E+00	.142E-04	.000E+00
THORIUM		.000E+00	.236E-04	< .364E-04
THULIUM		.000E+00	.709E-05	< .364E-04
TIN		.106E-02	.189E-03	.728E-04
TITANIUM		.159E+00	> .236E-01	.000E+00
TUNGSTEN		.000E+00	.210E-02	.146E-02
URANIUM		.000E+00	< .142E-04	< .364E-04
VANADIUM		.212E-02	.213E-03	.000E+00
YTTERBIUM		.000E+00	.473E-04	< .364E-04
YTTRIUM		.371E-02	.945E-03	.364E-04
ZINC		.159E+00	> .236E-01	.362E-01
ZIRCONIUM		.159E-01	.354E-03	.000E+00

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MASS/HEAT INPUT — BURLINGTON BASELINE — NG/J

ELEMENT	PROBE WASH	XAD-2	FIRST IMPINGER	2ND & 3RD IMPINGERS	BOILER OUTLET
ALUMINUM	> .204E-01	.272E-02	.000E+00	N .000E+00	> .467E-01
ANTIMONY	N .000E+00	N .000E+00	N .000E+00	< .239E-04	< .239E-04
ARSENIC	N .000E+00	< .299E-05	N .000E+00	N .000E+00	< .299E-05
BARIUM	> .204E-01	.000E+00	.000E+00	N .000E+00	> .116E+00
BERYLLIUM	< .204E-05	.000E+00	.000E+00	N .000E+00	.473E-05<X<.676E-05
BISMUTH	.204E-05	.000E+00	.000E+00	N .000E+00	.162E-04<X<.526E-04
BORON	.632E-02	.000E+00	.000E+00	N .000E+00	.198E-01
BROMINE	.224E-03	.000E+00	.000E+00	N .000E+00	.720E-03
CADMIUM	.204E-03	.000E+00	.000E+00	N .000E+00	.678E-03
CALCIUM	> .204E-01	.166E+00	U .000E+00	N .000E+00	> .355E+00
CERIUM	.346E-02	.000E+00	.000E+00	N .000E+00	.946E-02
CESIUM	.183E-04	.000E+00	< .376E-04	N .000E+00	.420E-04<X<.116E-03
CHLORINE	> .204E-01	.869E-01	.940E-02	N .000E+00	> .247E+00
CHROMIUM	.245E-02	.272E-02	.940E-03	N .000E+00	.879E-02
COBALT	.204E-03	.000E+00	.000E+00	N .000E+00	.642E-03
COPPER	.159E-02	.543E-02	.741E-02	N .000E+00	.195E-01
DYSPROSIUM	.122E-03	.000E+00	.000E+00	N .000E+00	.217E-03<X<.253E-03
ERBIUM	.204E-04	.000E+00	.000E+00	N .000E+00	.676E-04<X<.104E-03
EUROPIUM	.611E-04	.000E+00	.000E+00	N .000E+00	.108E-03<X<.145E-03
FLUORINE	> .204E-01	.109E-02	.000E+00	N .000E+00	> .393E-01
GADOLINIUM	.815E-04	.000E+00	.000E+00	N .000E+00	.200E-03<X<.236E-03
GALLIUM	.815E-04	.000E+00	.752E-03	N .000E+00	.999E-03
GERMANIUM	.204E-04	.000E+00	.000E+00	N .000E+00	.104E-03
HAFNIUM	.163E-04	.000E+00	.000E+00	N .000E+00	.163E-04<X<.527E-04
HOLMIUM	.408E-04	.000E+00	.000E+00	N .000E+00	.112E-03<X<.148E-03
IODINE	.408E-04	.000E+00	.376E-04	N .000E+00	.149E-03
IRON	> .204E-01	.353E-01	.000E+00	N .000E+00	> .841E-01
LANTHANUM	.285E-02	.000E+00	.000E+00	N .000E+00	.885E-02
LEAD	.489E-02	.000E+00	.752E-04	N .000E+00	.271E-01
LITHIUM	.204E-04	.000E+00	.000E+00	N .000E+00	.164E-03
LUTETIUM	.611E-05	.000E+00	.000E+00	N .000E+00	.156E-04<X<.520E-04
MAGNESIUM	> .204E-01	.000E+00	.752E-03	N .000E+00	> .448E-01
MANGANESE	> .204E-01	.000E+00	.376E-03	N .000E+00	> .533E-01
MERCURY	< .181E-04	< .120E-03	< .361E-04	< .239E-04	< .252E-03
MOLYBDENUM	.306E-03	.000E+00	.000E+00	N .000E+00	.960E-03
NEODYMIUM	.285E-03	.000E+00	.000E+00	N .000E+00	.985E-03
NICKEL	.245E-02	.951E-01	.677E-02	N .000E+00	.112E+00
NIOBIUM	.408E-04	.000E+00	.752E-04	N .000E+00	.236E-03
PHOSPHORUS	> .204E-01	.706E-02	.000E+00	N .000E+00	> .729E-01
PLATINUM	.000E+00	.000E+00	.000E+00	N .000E+00	.000E+00
POTASSIUM	> .204E-01	.196E+00	.000E+00	N .000E+00	> .243E+00
PRASEODYMIUM	.550E-03	.000E+00	.000E+00	N .000E+00	.105E-02
RUBIDUM	.224E-02	.000E+00	.113E-03	N .000E+00	.182E-01
SAMARIUM	.245E-03	.000E+00	.000E+00	N .000E+00	.730E-03
SCANDIUM	.163E-04	.000E+00	.000E+00	N .000E+00	.163E-04<X<.187E-04
SELENIUM	.143E-03	.000E+00	< .113E-02	N .000E+00	.841E-03<X<.197E-02
SILICON	> .204E-01	.122E+00	.000E+00	N .000E+00	> .166E+00
SILVER	.489E-03	.000E+00	.752E-04	N .000E+00	.115E-02
SODIUM	> .204E-01	.000E+00	U .000E+00	N .000E+00	> .440E-01
STRONTIUM	.189E-01	.000E+00	.000E+00	N .000E+00	> .459E-01
SULFUR	> .204E-01	.136E-01	> .298E+00	N .000E+00	> .356E+00
TANTALUM	< .204E-04	.000E+00	.000E+00	N .000E+00	.709E-04<X<.128E-03
TELLURIUM	.000E+00	.000E+00	.150E-03	N .000E+00	.167E-03<X<.203E-03
TERBIUM	.204E-04	.000E+00	.000E+00	N .000E+00	.676E-04<X<.104E-03
THALLIUM	.632E-03	.000E+00	.000E+00	N .000E+00	.646E-03
THORIUM	.204E-04	.000E+00	.000E+00	N .000E+00	.440E-04<X<.804E-04
THULIUM	.815E-05	.000E+00	.000E+00	N .000E+00	.152E-04<X<.516E-04
TIN	.102E-03	.000E+00	.000E+00	N .000E+00	.364E-03
TITANIUM	> .204E-01	.000E+00	.000E+00	N .000E+00	> .440E-01
TUNGSTEN	.815E-04	.000E+00	.000E+00	N .000E+00	.364E-02
URANIUM	< .183E-04	.000E+00	.000E+00	N .000E+00	< .689E-04
VANADIUM	.509E-03	.000E+00	.376E-04	N .000E+00	.760E-03
YTTERBIUM	.204E-04	.000E+00	.000E+00	N .000E+00	.676E-04<X<.104E-03
YTTRIUM	.387E-03	.000E+00	.000E+00	N .000E+00	.137E-02
ZINC	> .204E-01	.000E+00	.293E-01	N .000E+00	> .109E+00
ZIRCONIUM	.163E-03	.272E-02	.000E+00	N .000E+00	.323E-02

BURLINGTON

CONCENTRATION BASELINE MCG/DSCM

ELEMENT	10U + 3U	1U + FILTER	PROBE WASH	XAD-2	FIRST IMPINGER
ALUMINUM	> .393E+02	U .000E+00	> .339E+02	.452E+01	.000E+00
ANTIMONY	N .000E+00	N .000E+00	N .000E+00	N .000E+00	N .000E+00
ARSENIC	N .000E+00	N .000E+00	N .000E+00	< .497E-02	N .000E+00
BARIUM	> .393E+02	.119E+03	> .339E+02	.000E+00	.000E+00
BERYLLIUM	.785E-02	.000E+00	< .339E-02	.000E+00	.000E+00
BISMUTH	.236E-01	< .605E-01	.339E-02	.000E+00	.000E+00
BORON	.224E+02	.000E+00	.105E+02	.000E+00	.000E+00
BROMINE	.825E+00	.000E+00	.373E+00	.000E+00	.000E+00
CADMIUM	.668E+00	.121E+00	.339E+00	.000E+00	.000E+00
CALCIUM	> .393E+02	> .242E+03	> .339E+02	.275E+03	U .000E+00
CERIUM	.943E+01	.545E+00	.576E+01	.000E+00	.000E+00
CESIUM	.393E-01	< .605E-01	.305E-01	.000E+00	< .625E-01
CHLORINE	> .393E+02	.178E+03	> .339E+02	.145E+03	.156E+02
CHROMIUM	.393E+01	.545E+00	.406E+01	.452E+01	.156E+01
COBALT	.668E+00	.605E-01	.339E+00	.000E+00	.000E+00
COPPER	.668E+01	.169E+01	.264E+01	.903E+01	.123E+02
DYSPROSIUM	.157E+00	< .605E-01	.203E+00	.000E+00	.000E+00
ERBIUM	.785E-01	< .605E-01	.339E-01	.000E+00	.000E+00
EUROPIUM	.785E-01	< .605E-01	.102E+00	.000E+00	.000E+00
FLUORINE	.550E+01	.242E+02	> .339E+02	.181E+01	.000E+00
GADOLINIUM	.196E+00	< .605E-01	.135E+00	.000E+00	.000E+00
GALLIUM	.275E+00	.000E+00	.135E+00	.000E+00	.125E+01
GERMANIUM	.785E-01	.605E-01	.339E-01	.000E+00	.000E+00
HAFNIUM	.000E+00	< .605E-01	.271E-01	.000E+00	.000E+00
HOLMIUM	.118E+00	< .605E-01	.677E-01	.000E+00	.000E+00
IODINE	.118E+00	.000E+00	.677E-01	.000E+00	.625E-01
IRON	> .393E+02	.787E+01	> .339E+02	.587E+02	.000E+00
LANTHANUM	.943E+01	.545E+00	.474E+01	.000E+00	.000E+00
LEAD	.668E+01	.301E+02	.813E+01	.000E+00	.125E+00
LITHIUM	.118E+00	.121E+00	.339E-01	.000E+00	.000E+00
LUTETIUM	.157E-01	< .605E-01	.102E-01	.000E+00	.000E+00
MAGNESIUM	> .393E+02	.000E+00	> .339E+02	.000E+00	.125E+01
MANGANESE	> .361E+02	> .180E+02	> .339E+02	.000E+00	.625E+00
MERCURY	< .400E-01	< .502E-01	< .300E-01	< .199E+00	< .600E-01
MOLYBDENUM	.785E+00	.303E+00	.508E+00	.000E+00	.000E+00
NEODYMIUM	.982E+00	.182E+00	.474E+00	.000E+00	.000E+00
NICKEL	.118E+02	.157E+01	.406E+01	.158E+03	.113E+02
NIOBIUM	.785E-01	.121E+00	.677E-01	.000E+00	.125E+00
PHOSPHORUS	> .393E+02	> .363E+02	> .339E+02	.117E+02	.000E+00
PLATINUM	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00
POTASSIUM	> .393E+02	> .605E+01	> .339E+02	.325E+03	.000E+00
PRASEODYMIUM	.825E+00	.000E+00	.915E+00	.000E+00	.000E+00
RUBIDUM	.204E+02	.593E+01	.373E+01	.000E+00	.188E+00
SAMARIUM	.746E+00	.605E-01	.406E+00	.000E+00	.000E+00
SCANDIUM	< .393E-02	.000E+00	.271E-01	.000E+00	.000E+00
SELENIUM	.110E+01	.605E-01	.237E+00	.000E+00	< .180E+01
SILICON	> .393E+02	U .000E+00	> .339E+02	.203E+03	.000E+00
SILVER	.668E+00	.303E+00	.813E+00	.000E+00	.125E+00
SODIUM	> .393E+02	U .000E+00	> .339E+02	.000E+00	U .000E+00
STRONTIUM	> .393E+02	.557E+01	.315E+02	.000E+00	.000E+00
SULFUR	> .393E+02	> .000E+00	> .339E+02	.226E+02	> .496E+03
TANTALUM	.118E+00	< .605E-01	< .339E-01	.000E+00	.000E+00
TELLURIUM	.275E-01	< .605E-01	.000E+00	.000E+00	.250E+00
TERBIUM	.785E-01	< .605E-01	.339E-01	.000E+00	.000E+00
THALLIUM	.236E-01	.000E+00	.105E+01	.000E+00	.000E+00
THORIUM	.393E-01	< .605E-01	.339E-01	.000E+00	.000E+00
THULIUM	.118E-01	< .605E-01	.135E-01	.000E+00	.000E+00
TIN	.314E+00	.121E+00	.169E+00	.000E+00	.000E+00
TITANIUM	> .393E+02	.000E+00	> .339E+02	.000E+00	.000E+00
TUNGSTEN	.350E+01	.242E+01	.135E+00	.000E+00	.000E+00
URANIUM	< .236E-01	< .605E-01	< .305E-01	.000E+00	.000E+00
VANADIUM	.353E+00	.000E+00	.847E+00	.000E+00	.625E-01
YTTERBIUM	.785E-01	< .605E-01	.339E-01	.000E+00	.000E+00
YTTRIUM	.157E+01	.605E-01	.644E+00	.000E+00	.000E+00
ZINC	> .393E+02	.601E+02	> .339E+02	.000E+00	.488E+02
ZIRCONIUM	.589E+00	.000E+00	.271E+00	.452E+01	.000E+00

BURLINGTON

CONCENTRATION — BASELINE — MCG/DSCM

ELEMENT	2ND & 3RD IMPINGERS	BOILER OUTLET
ALUMINUM	N .000E+00	> .777E+02
ANTIMONY	< .397E-01	< .397E-01
ARSENIC	N .000E+00	< .497E-02
BARIUM	N .000E+00	> .192E+03
BERYLLIUM	N .000E+00	.785E-02<X<.112E-01
BISMUTH	N .000E+00	.270E-01<X<.875E-01
BORON	N .000E+00	.329E+02
BROMINE	N .000E+00	.120E+01
CADMIUM	N .000E+00	.113E+01
CALCIUM	N .000E+00	> .591E+03
CERIUM	N .000E+00	.157E+02
CESIUM	N .000E+00	.698E-01<X<.193E+00
CHLORINE	N .000E+00	> .411E+03
CHROMIUM	N .000E+00	.146E+02
COBALT	N .000E+00	.107E+01
COPPER	N .000E+00	.324E+02
DYSPROSIUM	N .000E+00	.360E+00<X<.421E+00
ERBIUM	N .000E+00	.112E+00<X<.173E+00
EUROPIUM	N .000E+00	.180E+00<X<.241E+00
FLUORINE	N .000E+00	> .654E+02
GADOLINIUM	N .000E+00	.332E+00<X<.392E+00
GALLIUM	N .000E+00	.166E+01
GERMANIUM	N .000E+00	.173E+00
HAFNIUM	N .000E+00	.271E-01<X<.876E-01
HOLMIUM	N .000E+00	.186E+00<X<.246E+00
IODINE	N .000E+00	.248E+00
IRON	N .000E+00	> .140E+03
LANTHANUM	N .000E+00	.147E+02
LEAD	N .000E+00	.451E+02
LITHIUM	N .000E+00	.273E+00
LUTETIUM	N .000E+00	.259E-01<X<.864E-01
MAGNESIUM	N .000E+00	> .744E+02
MANGANESE	N .000E+00	> .886E+02
MERCURY	< .397E-01	< .419E+00
MOLYBDENUM	N .000E+00	.160E+01
NEODYMIUM	N .000E+00	.164E+01
NICKEL	N .000E+00	.187E+03
NIOBIUM	N .000E+00	.392E+00
PHOSPHORUS	N .000E+00	> .121E+03
PLATINUM	N .000E+00	.000E+00
POTASSIUM	N .000E+00	> .404E+03
PRASEODYMIUM	N .000E+00	.174E+01
RUBIDUM	N .000E+00	.303E+02
SAMARIUM	N .000E+00	.121E+01
SCANDIUM	N .000E+00	.271E-01<X<.310E-01
SELENIUM	N .000E+00	.140E+01<X<.327E+01
SILICON	N .000E+00	> .276E+03
SILVER	N .000E+00	.191E+01
SODIUM	N .000E+00	> .731E+02
STRONTIUM	N .000E+00	> .763E+02
SULFUR	N .000E+00	> .592E+03
TANTALUM	N .000E+00	.118E+00<X<.212E+00
TELLURIUM	N .000E+00	.278E+00<X<.333E+00
TERBIUM	N .000E+00	.112E+00<X<.173E+00
THALLIUM	N .000E+00	.107E+01
THORIUM	N .000E+00	.731E-01<X<.134E+00
THULIUM	N .000E+00	.253E-01<X<.858E-01
TIN	N .000E+00	.605E+00
TITANIUM	N .000E+00	> .731E+02
TUNGSTEN	N .000E+00	.605E+01
URANIUM	N .000E+00	< .115E+00
VANADIUM	N .000E+00	.126E+01
YTTERBIUM	N .000E+00	.112E+00<X<.173E+00
YTTRIUM	N .000E+00	.227E+01
ZINC	N .000E+00	> .182E+03
ZIRCONIUM	N .000E+00	.538E+01